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Delivering multiple ecosystem services from Enclosed Farmland in the UK

Les Firbank[a,*], Richard B. Bradbury[b], David I. McCracken[c], Chris Stoate[d]

[a] School of Biology, University of Leeds, Leeds LS2 9JT, UK
[b] Conservation Science Department, RSPB, The Lodge, Sandy, Bedfordshire SG19 2DL, UK
[c] Scottish Agricultural College, Auchincruive, Ayr KA6 5HW UK
[d] Game & Wildlife Conservation Trust, The Allerton Project, Loddington, Leicester LE7 9XE, UK

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ABSTRACT

Here, we review the delivery of ecosystem services from Enclosed Farmland in the UK, and explore how the expected demands for ecosystem services might be met in the future. Most Enclosed Farmland is managed for agriculture; the UK is 60% self-sufficient in foods. Pollinators are in serious decline, but little is known of trends of predators of crop pests. Effects of agriculture on water quality and climate regulation are negative but improving; GHG emissions fell by 20% between 1990 and 2008. Recent declines in numbers of some farmland birds and in plant species richness have been halted, though not reversed. Enclosed Farmland provides considerable leisure and cultural value. Effective delivery of multiple ecosystem services requires improved understanding of how ecosystem services are generated, and of their economics and governance. Food production can be integrated with the delivery of other ecosystem services by promoting a diversity of farming systems and allocating land to different ecosystem services according to its suitability. Approaches include, minimising negative environmental impacts of food production through technology; mitigating environmental harm by managing areas for environmental benefit, from patches within fields to much larger areas; and developing markets and regulations for environmental protection.

1. Introduction

The global demands on ecosystem services from farmland will increase in coming decades as the human population increases (Millennium Assessment, 2005; Tilman et al., 2002). Clearly, greater amounts of agricultural products will be required, including food, fuel and materials, even if waste is reduced; there is an expectation that global agricultural production will have to increase by at least 50% by 2050 (Royal Society, 2009). However, increased production may well compete with the delivery of other services from agricultural land, such as water regulation and better control of externalities, such as diffuse pollution. The challenge is to deliver multiple ecosystem services simultaneously, optimised in ways that reflect their values to the many stakeholders involved. This is unlikely to be easy, given the significant differences among people in the value given to different services, as well as differences in the distribution of benefit flows, mediated by different levels of access to services and power relations within society (Bateman et al., 2011).

Here we address the issue of ecosystem service delivery from agricultural land in the UK by reviewing recent output trends in the ecosystem services delivered by Enclosed Farmland and how they might be managed in the future. Enclosed Farmland includes agriculture and horticulture in lowlands and marginal uplands, and is defined here following the UK Countryside Survey (Howard et al., 2003) as comprising the two Broad Habitats 'Arable and Horticultural' and 'Improved Grassland'. It is therefore characterised by vegetation cover (i.e. crops, stubbles and grassland that is relatively poor in species and high in nutrient status) rather than land use. It is typically bounded by linear features such as hedgerows, ditches, grass strips and fences. Open farmland in the uplands is excluded, as are the more species-rich habitats of Acid, Neutral and Calcareous Grasslands. This analysis is part of the UK National Ecosystem Assessment (UKNEA), that sought to evaluate the benefits provided by every major habitat type in the UK in terms of the major provisioning, supporting, regulating and cultural services, their values and trends, the major drivers of change and options for the sustainable delivery of ecosystem services (UKNEA, 2011). It builds upon the Millennium Ecosystem Assessment (Millennium Assessment, 2005), and links the drivers of change (direct and indirect) to changes in biodiversity, ecosystem goods and services, and hence human wellbeing.

Enclosed Farmland is managed primarily for the provisioning of food. But it is important for many other ecosystem services, not least because it covers such large areas. It is the most widespread habitat in the UK, accounting for 39.3% of the land area in 2007, with

* Corresponding author. Tel.: +44 113 343 2859.
E-mail address: l.firbank@leeds.ac.uk (L. Firbank).

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Arable and Horticultural and Improved Grassland accounting for 18.8% and 20.5% of UK land cover respectively (Carey et al., 2008). While this paper addresses the UK, the issues are similar among many of the more intensive agro-ecosystems across Europe. The land areas involved are large: in 2007 over 41% of the land area of the European Union (EU27) was under agriculture; 61% of that 172 million ha of agricultural land was classified as arable and 6% was classified as permanent crops, while much of the remaining 33% classified as permanent grassland (Olsen, 2010) is likely to be improved grassland.

2. Ecosystem services derived from Enclosed Farmland

Here we summarise recent trends in delivery of provisioning, supporting, regulating and cultural ecosystem services within UK Enclosed Farmland, as defined within the UKNEA (UKNEA, 2011), following the Millennium Assessment (2005) (Table 1).

2.1. Provisioning services

2.1.1. Food production

The UK is currently 60% self-sufficient in all foods, and 73% self-sufficient in indigenous foods, a figure that has fallen slightly since the 1990s (Defra, 2010a). In 2009, the area of cereals planted in the UK was 3.1 million ha, producing just over 22 million tonnes of grain (Defra, 2010a), more than enough for the country's processing needs, with a decline in barley and increase in wheat, albeit with much annual variation (Fig. 1). Average wheat yields in the UK have risen from 2.5 tonnes ha^{-1} yr^{-1} in 1940 to the present 7.9 tonnes ha^{-1} yr^{-1}. Over the past decade, there is little evidence of national yield increases in wheat, barley or oilseed rape (Defra, 2010a), in spite of the regular introduction of new varieties that provide higher yields in experimental plots.

Historically, most young grasslands were grass-clover mixes, in rotation with arable crops to restore fertility and provide hay. During the course of the 20th century, these have been replaced by regularly reseeded long-term leys, designed to maximise production of grazing or silage for feeding to stock over-winter, supplemented by concentrates and sometimes forage crops. Heterogeneity of sward structure has declined as a result (Wilson et al., 2005). The number of animals required to produce each tonne of meat has fallen by 5% from 3.23 in 1998 to 3.07 between 1998 and 2008 (EBLEX, 2009). Cattle numbers in the UK fell in the mid 20th century, but then livestock numbers rose until the 1990s, sustained by increasing inputs of inorganic fertilisers and feed; they have since fallen again to around 1.9 million dairy and 1.6 million beef cattle and 32 million sheep (Defra, 2010a).

In 1951, the 1 million agricultural workers represented 5% of the British workforce, while the present figure of 470,000 agricultural workers now constitutes fewer than 2% of the total, suggesting a redistribution of the economic benefits of food production. Globally, there was a halving of the prices of major food-stuffs in the 50 years up to 2006 (IMF, 2006). However, since then the FAO's index of global food prices has nearly doubled (FAO, 2011) and the global number of hungry people has increased (FAO, 2010).

In summary, the provisioning of food increased from UK Enclosed Farmland until the mid-1980s, after which it has largely stabilised, albeit with greater efficiency of production from fewer animals in the livestock sector.

2.1.2. Bioenergy production

The area of agricultural land under bioenergy crops is increasing in the UK, but from a very low base (Lovett et al., 2009). In terms of biomass crops, the area of *Miscanthus* spp. was 12,600 ha in 2007, and planting had been approved for over 3700 ha of short rotation coppice (Sherrington and Moran, 2010). Farm woodlands are rarely planted primarily for timber and fuel, but the recent widespread adoption of wood fuel boilers on farms has encouraged the production of wood chip and logs from a wide range of woodland types. The use of plant biomass for heating in the UK is thought to have been around 72,000 tonnes of oil equivalent from 1990 to 2004, rising to over 200 in 2009, while the generation of electricity from plant biomass has increased from 0 in 1997 to 364,000 tonnes of oil equivalent in 2009 (out of a total demand of 16,484), when the UK consumed 212 m tonnes of oil equivalent total primary energy (DECC, 2010). In summary, this service is now increasing from a very low base, and remains a very small component of the UK energy supply.

2.2. Supporting services

2.2.1. Pollination

Some farmland taxa have clear functional roles supporting agricultural production. Insects that contribute to pollination include bumblebees, honey bees, solitary bees, hoverflies, butterflies and moths. Pollinator-dependent crops covered 23% of UK cropped area in 2007, when the annual value of insect pollination was estimated to be £430 million (Defra, 2008, 2009; Basic Horticultural Statistics, 2008). Honeybee (*Apis mellifera*) colony numbers declined severely between 1985 and 2005 (Potts et al., 2010a). Similarly, wild bees and hoverflies are in serious decline, with more than half of UK landscapes studied showing a significant loss of bee diversity (Biesmeijer et al., 2006). Drivers of wild pollinator declines include the loss of flower-rich landscape elements in farmland (Winfree et al., 2009), the loss of grass/clover leys (Carvell et al., 2006), and improved weed control (Roy et al., 2003). Pesticides have been shown to have lethal and sub-lethal effects on bees (Morandin et al., 2005), and can result in local loss of bee diversity (Brittain et al., 2010). No data are available on trends in the actual levels of pollination, or on the impact of pollinator declines on UK food production. However, models developed and tested at a global level have indicated that crops with greater pollinator dependence have lower mean relative yield and yield growth, despite global yield increases for most crops, and that cultivation areas of pollinator-dependent crops have been increased. These results suggest that pollen limitation is hindering yield growth of pollinator-dependent crops, while promoting compensatory land conversion to agriculture (Garibaldi et al., 2011).

2.2.2. Biological pest control

Biological pest control is provided by a wide range of invertebrate predators and parasitoids, such as carabid beetles, spiders and ladybirds (e.g. Schmidt et al., 2003; Holland et al., 2005). Epigeal predators associated with grass margins have been shown to reduce cereal aphid numbers in adjacent fields by 40%, while more mobile flying predators reduced numbers by 90% (Holland et al., 2008). Little is known of trends in national populations of these invertebrates.

2.3. Regulating services

Soil organisms cycle nutrients and carbon, though our understanding of the mechanisms by which soil biodiversity influences ecosystem processes and the delivery of supporting services, and how it responds to land management, is limited (Bardgett and Wardle, 2010). For example, recent studies suggest that mycorrhizal soil fungi may have potential to influence phosphate availability to crop plants (Ehinger et al., 2009).

2.3.1. Climate regulation

Agriculture has a potential positive effect on climate regulation in that carbon sequestration is possible in soils and vegetation, and

Table 1
Overview of major ecosystem services provided by Enclosed Farmland (the values range from ++, through 0 to −−, depending on the magnitude and direction of influence). This table summarises evidence given in the text from reports, databases and the literature: see also (Firbank et al., 2011).

Final ecosystem service	Importance of Enclosed Farmland for service	Impact of Enclosed Farmland on service	Trend since 1950	Evidence base	Comments
Provisioning of food	High	++	Strong increase until mid-1980s, since when it has been largely stable	High agreement, much evidence	Strong positive score: farmland is largely managed for crop and livestock production
Climate regulation	High	−−	Ongoing reduction in negative impacts	High agreement, much evidence	Strong negative score, due to emissions of GHGs, depletion of carbon in arable soils and low but rising use of bioenergy
Regulation of water quantity	High	+/−	Trend data are lacking	High agreement, much evidence	Important for catching water for ground and surface waters, though flood risk mitigation potential often compromised by management
Waste breakdown and detoxification	High	−−/+	Reduction in negative impacts since 1990; inadequate data before this date	High agreement, much evidence	Negative score due to diffuse (mainly) pollution leaving farmland; positive score for ability to compost green waste/AD, and sewage disposal
Wild species diversity, including microbes	High	−−	Declines in diversity and abundance of species, but the service has become more widely valued	High agreement, much evidence	Negative impacts; status of microbes unknown
Meaningful places and green and blue space	Low	0	Inadequate evidence of trend	High agreement, limited evidence	Enclosed Farmland is of low importance per unit area compared with urban parks, mountains etc.
Socially valued landscapes and waterscapes	High	++	Inadequate evidence of trend	High agreement, limited evidence	Farming management is largely responsible for the rural landscapes that many people cherish

bioenergy crops can be substituted for fossil fuels. Arable soils tend to be depleted in carbon (Smith et al., 2000a,b). By contrast, permanent grassland soils contain more carbon per unit area (Bradley et al., 2005), but are already close to carbon saturation, making them more important carbon stores than potential sinks. Conversion of temporary grassland or arable to permanent grassland and, especially, to woodland, tends to lead to an increase in carbon sequestration, while the cessation of cultivation, especially of peat

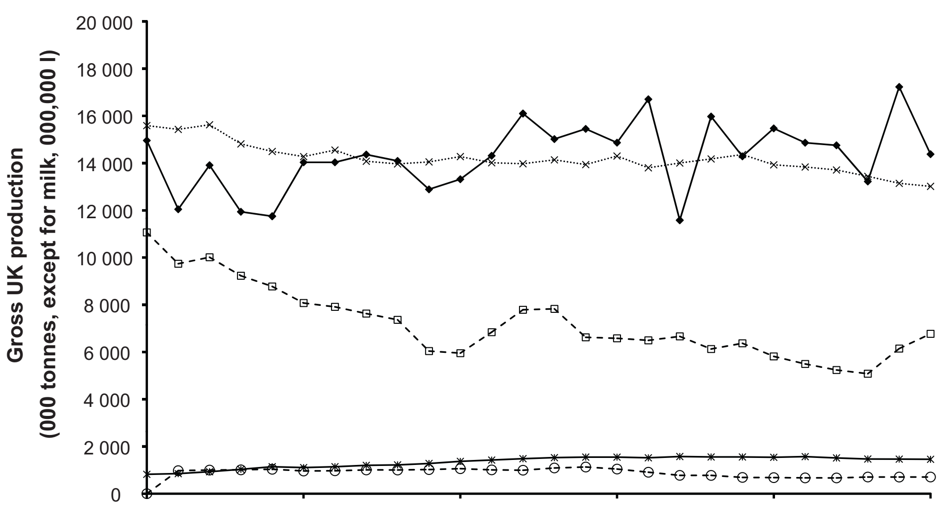

Fig. 1. Gross UK production over time of exemplar crops produced largely from Enclosed Farmland; wheat (solid line, closed diamonds); barley (dotted line, open squares); pig meat (dashed line, open circles); poultry meat (solid line, stars) and milk (dotted lines, crosses). All units 000 tonnes, except for milk for which units millions of litres.
Source: Defra (2010a).

soils, reduces CO_2 losses (Smith et al., 2008). The large scale conversion of unimproved grassland to arable and improved grassland in the mid-20th century (Fuller, 1987) must have been accompanied by large scale emissions of CO_2, but these have not been quantified.

UK agriculture currently has a negative effect on climate regulation, generating net GHG emissions that account for around 7.0% of the UK total, comprising 69% of emissions of N_2O and 38% of methane emissions, as well as CO_2 from use of farm machinery (Defra, 2010a). N_2O emissions are especially associated with the oxidation of the nitrogen in inorganic and organic fertilisers. Methane emissions from the agriculture sector mainly arise from manures and from enteric fermentation that occurs in the digestive systems of ruminants. They are driven by the number of livestock animals, their productivity (more productive animals produce less methane per unit of meat), their diet, and how manures are managed (Committee on Climate Change, 2010).

Agricultural emissions fell by around 20% between 1990 and 2008 (Defra, 2010a), thanks largely to a decline in methane emissions as a result of reductions of both livestock numbers and fertiliser use. Note that such reductions contribute to improved climate regulation only if they are not matched by increases elsewhere as a result of shifts in trade (Gill et al., 2010). In summary, then, it seems likely that negative effects of Enclosed Farmland management on climate regulation, though still important, have declined over recent decades.

2.3.2. *Water quantity, hazard regulation, waste breakdown and detoxification, purification*

River water and groundwater are important resources for agriculture. Although water used for agriculture represents only about 2.0% of that abstracted in the UK, much is used in the summer in the south and east of England, already a time and place of high demand for agriculture and domestic use (Defra, 2010a). Plant cover, root architecture, drainage, field and watercourse boundary management all contribute to speeding up or slowing the movement of water through farmland, although these effects are easily masked at the catchment scale. Biomass crops, for instance, are fast growing and consume large amounts of soil water, while grasses, trees and other waterside vegetation can slow down run-off, thereby attenuating flooding, and helping to reduce diffuse pollution (Bilotta et al., 2007; Pilgrim et al., 2010).

While Enclosed Farmland can contribute positively to waste breakdown, for example through composting and the application of digestates from biogas plants, most impacts are currently negative. From a European perspective, diffuse pollution from agriculture remains the biggest threat to recreational waters, through reductions in water quality caused by contaminated run-off water. Contaminants include sediments, nitrogen and phosphorus that can be lost from both arable and intensive grassland systems (Foster, 2006; McIntyre et al., 2009; Bilotta et al., 2010), as well as parasites that impact on human health, transmitted from livestock faeces, e.g. *Escherichia coli* 0157:H7 (FAO, 2006) and *Cryptosporidium* (Patz et al., 2004).

Agriculture now accounts for some 60% of nitrates in rivers, resulting from the leaching of excessive application of nitrogen (Defra, 2010a). Lowland river quality has improved greatly over the past two decades (Defra, 2010a: Fig. 2), resulting partly from the decline in synthetic nitrogen applications on grassland from 129 to 55 kg ha^{-1} (57%) between 1990 and 2008, related to falling stocking densities; application rates on arable land have remained fairly constant at around 140–150 kg ha^{-1}. Excess nitrogen also gives rise to soil acidification and atmospheric emissions of N_2O, and is associated with the trend of much lowland vegetation becoming more homogenous and typical of higher nutrient status (Smart et al., 2006).

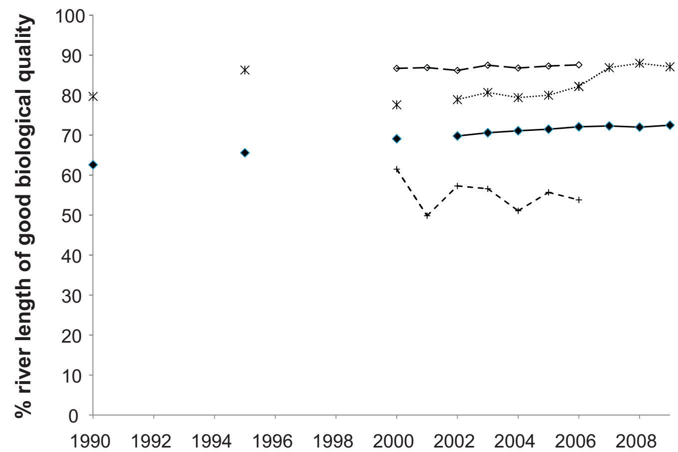

Fig. 2. Percentage of total river length that is of 'good' biological quantity for England (solid line, solid diamonds), Northern Ireland (dashed line, crosses), Scotland (dashed line, open diamonds) and Wales (dotten line, stars). From Defra (2010b). Note increasing frequency of measurements since 2000.

Ammonia is released by the breakdown of urea and uric acid from urine and poultry faeces, and can result in soil acidification. It can also be dispersed through the air and in rainfall, to be deposited on soils and vegetation, acidifying and adding ammonium, and causing an odour nuisance and negative impacts on biodiversity in both terrestrial and aquatic environments (Maier et al., 2008). In 2007, 91% of UK ammonia emissions were from agriculture (Defra, 2010b), predominately from livestock housing and from the spreading of animal manure. The total emissions of ammonia for 2007 are estimated at 0.29 Mt, a 21% reduction from 1990, due primarily to declining livestock numbers (Jackson et al., 2009) and reduced fertiliser use (Defra, 2010b).

The total amount of phosphate applied to farmland also fell between 1990 and 2008, by 54% on arable land and 53% on grass (Defra, 2010a). Phosphorus loss from farmland is often associated with sediment loss; agricultural sources account for between 29% and 90% of phosphate in rivers (White and Hammond, 2006; Jarvie et al., 2010), with increased risk of eutrophication (Maier et al., 2008).

The use of pesticides has changed greatly over time, in response to technologies and regulation. Amounts of active ingredient ha^{-1} have tended to fall since the late 1980s (Defra, 2010a), and direct unintended impacts of pesticides are now localised and have been reduced by technological improvements in the precision of spraying. By contrast, indirect effects on biodiversity by removal of animals and, especially, arable plants at the bottom of the food chain remain high (Marshall et al., 2003) and could be exacerbated by the widespread use of herbicide-tolerant crops (Gibbons et al., 2006).

In summary, we lack data on the ecosystem benefits of flood control, water regulation and purification. High quality data on the disservices of pollution to water and atmosphere are available from 1990, since when pollution levels have tended to fall.

2.4. *Cultural services*

2.4.1. *Sense of place and aesthetics*

The Enclosed Farmland of the UK is characterised by a diversity of scenery and habitat, influenced by, and valued by, many people and institutions. In the UK, the defining senses of place appear to be built around typically rural landscapes (Weiner, 2004). Field systems are generally highly valued, especially if small scale and irregular, such as those of traditional pastoral landscapes. Hedgerows are quintessential and locally distinctive features which reflect cultural history, conserve outlines of past land use, and define many rural landscapes. Traditional farm buildings provide a wide range of cultural benefits across all but the most remote landscapes of England (Gaskell and Owen, 2005; Countryside Agency, 2006).

2.4.2. Leisure

Exercise in the countryside takes several forms and has significant health benefits (Pretty et al., 2007). There are an estimated 1 million horses in the UK, and 4.4 million people riding at least once a year (Commission for Rural Communities, 2008); most are kept and ridden on Enclosed Farmland. Around 370,000 people regularly shoot game in England, and this activity supported around 54,000 full-time equivalent jobs and influenced the management of over 8.5 million ha of countryside (PACEC, 2006). Management for game shooting contributes directly to the conservation of birds and other wildlife (Draycott et al., 2008). More than 170,000 people made educational visits to farms in England in 2008 (Natural England, 2009).

2.4.3. Wild species diversity

Enclosed Farmland is associated with a suite of species favoured by habitats that are early successional, open, disturbed and/or in ecotones and mosaics with woodland. Some farmland taxa, such as the skylark, have strong cultural importance and particular resonance with the public, perhaps fostered by their widespread distribution and proximity to settlements (Mabey, 1997; Crocker and Mabey, 2005).

Changes in agricultural practices must have always resulted in population ebbs and flows, according to which species were best suited to the prevailing land management regimes (Shrubb, 2003; Firbank, 2005). However, in recent decades, the management of Enclosed Farmland has been strongly detrimental to wild species diversity (Firbank et al., 2008), with major declines in diversity and numbers of plants, terrestrial invertebrates and vertebrates (Potts, 1986; Rich and Woodruff, 1996; Ewald and Aebischer, 1999; Chamberlain et al., 2000; Robinson and Sutherland, 2002; Shrubb, 2003; Wilson et al., 2009; Potts et al., 2010). It is hard to quantify longer-term trends, given that they started well before biological recording systems had been established. However, the UK population of farmland birds almost halved between the 1970s and early 1990s, though remaining relatively stable since (Fig. 3). There are signs that some population declines have been halted, though not reversed. Plant species richness in UK arable habitats increased between 1990 and 2007, after showing a decline between 1978 and 1990 (Carey et al., 2008), while the numbers of farmland bird and butterfly food plant species in arable fields increased by 22% and 24% respectively between 1998 and 2007 (Carey et al., 2008).

Though these data imply that changes in abundance will have had impacts on cultural ecosystem services, quantifying such impacts is not yet possible. In general, we lack national, time-series data on cultural services associated with Enclosed Farmland.

3. Major drivers of change

While there have been many drivers of change to Enclosed Farmland habitats (Table 2), the major ones to date have been technological, market and policy related. While they may have been separately targeted at a single service (usually food production), they have tended to operate synergistically by influencing land management, with consequences for other services.

3.1. Technology

Technology has resulted in large increases in food production per unit of land and, in the process, has influenced the Enclosed Farmland habitat greatly, along with the ecosystem services it provides. In the 1930s, there were few arable-only farms (Stamp, 1950). The introduction of inorganic nitrogen fertilisers and draught animals reduced the need for mixed farming and legumes in rotations (Shrubb, 2003). In arable areas, ponds and hedgerows were no longer needed for watering and containing livestock. Now, landscapes have been simplified and largely polarised between arable crops in the drier and more fertile south and east of the UK, while pasture-based stock rearing dominates in the west (Robinson and Sutherland, 2002; Benton et al., 2003; Haines-Young et al., 2003; Stoate, 1995, 1996). Plant breeding and the use of fertilisers and pesticides have resulted in high yielding, denser cereal stands (Costigan and Biscoe, 1991) and the replacement of hay by faster-growing silage (Vickery et al., 2001), while genetic and management improvements raised milk production by the average cow from 5000 $l\,yr^{-1}$ in 1989 to 7600 $l\,yr^{-1}$ in 2007 (Dairy Supply Chain Forum's Sustainable Consumption and Production Taskforce, 2008; see also Hendrickson and Miele, 2009).

3.2. Changes in markets

Following the food shortages of WWII, the 1947 Agriculture Act mandated an intensification of food production to ensure UK self-sufficiency, facilitated by price support (Tracy, 1989). Price support continued within the Common Agricultural Policy (CAP), which initially aimed to increase productivity and provide more food at a lower cost for EU countries, while also achieving a fair standard of living for farmers. This policy was very successful, and led to over-production in the EU in the 1980s, and the introduction of set-aside to control production levels. The recent slowdown of yield increases may be due to farmers managing the crop for profit by controlling input costs rather than yield maximisation, and to more variable weather patterns (Bridge and Johnson, 2008). After a period of relatively low food prices, global food prices rose sharply during 2007 and 2008. High prices are expected to continue because of economic growth (especially in developing countries), increased demand for animal feeds, rising biofuel production, and anticipated higher costs of energy related inputs (OECD-FAO, 2010). Consumer action has included resistance to GM crops in Europe and increasing markets for food produced locally and with social and environmental added value, met by increasingly integrated food chains (Anderson and Firbank, 2009).

3.3. Increased policy requirement for environmental quality

Concerns grew that the production paradigm of the 1970s promoted agricultural production at the expense of the environment, notably water quality, the amount and condition of natural and semi-natural habitats, farmland biodiversity and, most recently, greenhouse gas (GHG) emissions. Technological responses included ways to manage agrochemical and nutrient inputs through precision, integrated and organic farming systems. Policy responses included reform of the CAP, and the introduction of agri-environment schemes, regulations such as the Water Framework Directive, and targets for production of renewable energy (DTI et al., 2007) and reduction of GHG emissions (HM Government, 2009).

3.4. Climate change

The UK is expected to become warmer, with the south and east tending to become drier and the rest of the UK wetter (Jenkins et al., 2009). These changes are part of much larger global changes in climate that are expected to have major impacts on patterns of global food production and hence trade (Parry et al., 2007). Some UK farms are already introducing crops of hotter climates, including

Table 2
Drivers of change of the Enclosed Farmland habitat. This table summarises evidence given in the text from reports, databases and the literature: see also Firbank et al. (2011).

Driver	Relevant to farmland now and in future	Major driver on farmland	Evidence base
Climate change (temperature/precipitation)	Becoming relevant	Mitigation and adaptation	High agreement, much evidence
Land use/land cover	Yes	Yes, especially exchanges between grass and arable	High agreement, much evidence
External inputs–unintended (pollution)	No	No	High agreement, limited evidence
External inputs–intended (nutrients etc.)	Yes	Yes, fertilisers, pesticides. Inputs likely to reduce	High agreement, much evidence
Harvest/resource use (e.g. stocking rates)	Yes	Responds to other drivers	High agreement, much evidence
Technology adaptation	Yes	Mechanisation, precision agriculture, new varieties	High agreement, much evidence
Market forces	Yes	Not just for food, but also energy, input costs, carbon etc.	High agreement, much evidence
Government subsidies	Yes	Influences land management choices	High agreement, much evidence
Regulation	Yes	Influences land management choices	High agreement, much evidence

melons, kiwi fruit, olives and even tea (The Times, 9 August 2010). Extremes of weather threaten the resilience of livestock management, for example if the land is too wet for cattle to be put out to graze or too dry for adequate silage production, while arable farming is likely to face water stresses in summer. A potential benefit of elevated carbon dioxide (CO_2) levels is enhanced yields of C_3 pasture plants, common in temperate systems (Long et al., 2004), albeit at a potential cost of reduced plant protein content (Cotrufo et al., 1998).

4. How to improve delivery of ecosystem services from Enclosed Farmland

The management of Enclosed Farmland in the UK, and indeed across Europe, currently has positive outcomes for agricultural production, but outcomes for supporting, regulating and cultural services tend to be negative: more productive agricultural management tends to give rise to external costs, rather than external benefits (Pretty et al., 2000; Henle et al., 2008). For example, within European temperate grasslands, increasing agricultural production consistently results in negative impacts on air quality, water quality, biodiversity, erosion regulation, nutrient cycling and landscape quality. By contrast, interactions among the non-agricultural production ecosystem services tend to be positive (Pilgrim et al., 2010).

It seems that the goals of multifunctional agriculture, in which the full range of economic, social, cultural and environmental functions of agriculture are recognised and maintained, have not been widely met in practice. What needs to change in order to increase the delivery of all major ecosystem services in agricultural landscapes? Here we review several approaches; these are not mutually exclusive.

4.1. Minimising negative impacts of agricultural production

One response to concerns over food security is to enhance agricultural productivity while minimising negative impacts on other ecosystem services. This is primarily a call for new technologies, including genetic modification, that increase provisioning of food and energy, while increasing efficiency of resource use, notably water, carbon and nutrients. Competition is thereby reduced, for these resources and improving the regulation of air, water and climate (Royal Society, 2009).

The recent declines in GHG emissions and diffuse pollution indicate more efficient resource use in agriculture. But far more can be done. More precise soil, fertiliser and agrochemical management has the potential to reduce diffuse pollution and GHG emissions (Smith et al., 2008; Macleod et al., 2010). Methane emissions from stored manures and slurries can be reduced through the installation of anaerobic digestion (AD) plants to generate energy, and by covering and aerating slurry and manure while stored (Committee on Climate Change, 2010). More efficient use of water can be delivered through more water-efficient crops, more targeted management of soils, more efficient irrigation systems, the use of greenhouses and

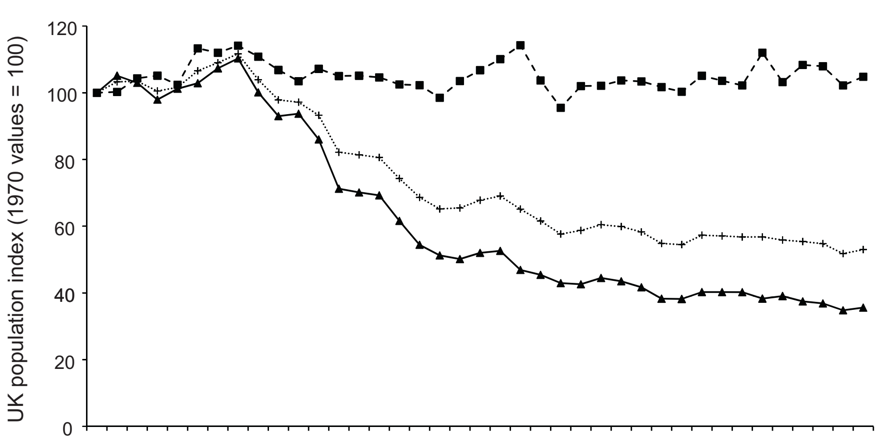

Fig. 3. Populations of UK farmland birds, 1970–2008, as an index (1970 populations = 100). Trends are shown of farmland generalists (7 species, dashed line, solid squares), farmland specialists (12 species, solid line, solid triangles) and of all 19 farmland species (dotted line, crosses).
Source: Defra (2010b).

plastic tunnels, and the use of non-conventional water resources (including treated waste water and harvested rain).

The poorer quality nutrition and longer production times of hill sheep mean much higher GHG emissions per kg of lamb produced, because lower quality forages tend to generate higher methane emissions, and slow growth results in greater emissions than more rapid growth and earlier slaughter. Thus, lowland sheep flocks produce 12.6 kg CO_2e kg^{-1}, compared with upland flocks (13.8 kg CO_2e kg^{-1}) and hill flocks (18.4 kg CO_2e kg^{-1}) (EBLEX, 2009). Animal breeding can be used to reduce GHG emissions per unit of livestock production by influencing productivity and fertility (respecting animal welfare concerns) and modifying diets to reduce enteric fermentation (e.g. use of maize-silage and avoidance of high fibre forage that stimulates methane production) (Committee on Climate Change, 2010). A switch from ruminants to pigs for meat may prove valuable, because they produce far less methane (Sneddon et al., 2010), and they can feed on a greater variety of protein sources, including waste, thereby potentially reducing the need for animal feed crops. But such changes may have negative impacts on other ecosystem services; thus, for example, reductions in numbers of livestock in the uplands may impact on vegetation and hence cultural services from upland landscapes. Changes in animal diets influence meat characteristics (Priolo et al., 2002); there is evidence that cattle fed on grass can produce higher quality meat (Scollan et al., 2006), while fodder maize production can result in significant soil erosion and has little biodiversity value.

4.2. Mitigating environmental harm of agricultural production

Mitigation is the use of techniques that offset inescapable environmental harm from agricultural practices, often by managing some parts of the farm differently to others or removing small areas from food production (Smukler et al., 2010). Indeed, at the research and demonstration farms of both RSPB and the Game and Wildlife Conservation Trust (GWCT), strategic removal of relatively small areas from production and into targeted wildlife habitat has led to considerable increases in farmland bird numbers (Firbank et al., 2011).

Field edges are particularly suitable, as they tend to be less productive than field centres in terms of food, but are often richer in biodiversity. Thus, conservation headlands were proposed as a way of mitigating the effects of pesticides and herbicides on arable biodiversity by reducing the choice of sprays to be used in the field edges (Sotherton, 1991). Grass field margins can be sown to provide habitat for pollinating insects, predators of crop pests and nesting birds and, if sited strategically, they can also reduce overland sediment and nutrient runoff to watercourses (Borin et al., 2004; Bradbury et al., 2010). Field edge detention ponds and constructed wetlands can be used to trap phosphorus lost from field drains to watercourses (Stoate et al., 2006). It has been suggested that expected reductions in arable plants and invertebrates in genetically modified herbicide tolerant beet could be offset by leaving 4% of field area unsprayed with herbicide (Pidgeon et al., 2007).

Land segregation into some areas which focus on food production and others which focus on other ecosystem services could happen over a continuum of scales, from the within- or between-field scale to landscape scales (e.g. Balmford et al., 2005; Phalan et al., 2011). At a landscape scale, such 'land sparing' involves using some areas for intensive agriculture, and protecting other zones for habitat conservation and other functions. This contrasts with 'land sharing' approaches, which involve adoption of more extensive farming systems, to provide multiple services from the same area, though with perhaps lower efficiency per unit area (Phalan et al., 2011). Land sparing recognises that not all ecosystem functions are compatible with agriculture, not least biodiversity conservation. However, it cannot be assumed that agricultural intensification automatically results in land sparing elsewhere that delivers other benefits; the 'spared' land may already be degraded, or given an alternate use (e.g. bioenergy). The optimum solution, and scale of sharing/sparing, depends on the suitability of the different areas for the different ecosystem services being considered (e.g. Hodgson et al., 2010) and how they are valued.

4.3. Integrated land management systems

While research has not reached the point where validated models are available to deliver spatially explicit, optimised farmland planning and management, there are many management options that will help deliver multiple ecosystem services from Enclosed Farmland. Space does not allow a detailed consideration of all such options, but we provide below three examples of options which could be implemented at an individual field level and two examples of options that would require changes at the farming systems and landscape scale.

4.3.1. Soil management

Soil function is central to many supporting, regulating and provisioning services; ideally, soil should cycle nutrients and support plant growth, with minimum loss of sediments and nutrients to water, minimum loss of N_2O and should sequester carbon.

Minimum and no-tillage can reduce negative impacts of cultivation on water quality, improve soil function, reduce energy needs for cultivation and deliver some biodiversity benefits (Holland, 2004; Field et al., 2007a,b). However, while there are suggestions of carbon sequestration benefits, there is also evidence to suggest that carbon may be redistributed within the soil, rather than sequestered, and that N_2O emissions can be increased because of low soil aeration and increased waterlogging (Bhogal et al., 2008). In addition, there is a possibility of increasing overland flow and flood risk in comparison with traditional tillage practice, at least in autumn, and in the early stage of conversion, that herbicide use can be increased.

Climate regulation may be improved by using nitrification inhibitors that reduce N_2O emissions arising from fertiliser application (Committee on Climate Change, 2010). Even without land use change, Enclosed Farmland could potentially be used to sequester large amounts of carbon through the more efficient use of organic amendments, changed residue management and possibly tillage, and to reduce emissions by restoring farmed organic soils such as peats (Smith et al., 2000b, 2008).

4.3.2. Arable rotations

Crop rotations that include legumes followed by deep-rooted crops could help in regulating water quality and climate, as less fertiliser inputs would be needed, reducing nitrate leaching to surface and groundwater, losses of N_2O and fewer emissions from fertiliser manufacture. Fertiliser use may be reduced from arable systems by relying more on organic fertilisers, e.g. from urban composts, biogas digestates and sewage, or from animal production systems, either on-farm or nearby. More radically, a switch from annual to perennial crops may be beneficial, as regular soil disturbance is avoided (Glover et al., 2010), allowing carbon sequestration into arable soils.

4.3.3. Bioenergy and biorefinery systems

One approach to managing poorer quality agricultural land is to use it for biomass for energy or as an industrial feedstock, where topography and soil type permit mechanical operations. Bioenergy cropping should promote climate regulation, but conversion of grassland to energy crops results in a loss of carbon from the soil that may take many years to recoup (a decade in the case of short rotation coppice, Hillier et al., 2009). There is increasing interest is using grasses as biorefineries for industrial products (Mandl, 2010);

the on-farm environmental impact of these plants need be little different from any other re-seeding of established grasslands, but would compete for land with meat and dairy production systems.

4.3.4. Livestock and mixed farming systems

Livestock production systems are most efficient, in terms of resource utilisation and GHG emissions, if the animals grow rapidly and are in good health, if manures are used for nutrients and, possibly, energy, and if they are not in competition with human consumption of plant material. GHG emissions are associated more with ruminants than other livestock. Lowland farms that produce pigs and chickens within purpose-built housing and with efficient manure management facilities, will contribute the least to GHG emissions, and minimise competition between land used to grow crops for fodder versus food. However, such enterprises are likely to have a negative impact on cultural services by changing landscape aesthetics (not to mention animal welfare perceptions). Therefore, even if such systems win public support, there will be a place for less intensive livestock systems (e.g. organic, upland) to serve consumer choice and for landscape and habitat management.

4.3.5. Multifunctional farming systems

One can integrate the provision of ecosystem services across the farm, landscape or catchment according to topography, soil type, and energy costs on the one hand, and to markets, regulations and the objectives of the landholders on the other. This is hardly a novel concept; it has driven traditional farming systems that needed to be multifunctional in terms of food, fuel, shelter and materials.

Of course, there are many different kinds of farming systems that seek to integrate food production with other ecosystem services. Organic farming promotes the internalisation of inputs for crop and livestock production, especially in the case of nutrients. In contrast to integrated farming, organic production precludes the use of many external inputs, such as mineral fertilisers and most pesticides (Lampkin, 1990; Norton et al., 2009). UK Soil Association standards preclude the use of GM crops and feeds. Levels of biodiversity tend to be higher than conventional systems, per unit area, as organic systems tend to have more diverse landscapes and habitats (Fuller et al., 2005). However, food production levels are typically lower than non-organic systems, too low for organic-only systems to feed the world given current technologies and the aspiration for meat-rich diets (Goulding et al., 2009).

Ecoagriculture is a general approach that focuses on the integration of food production with biodiversity conservation and other ecosystem services through landscape-scale design and management, using the concepts of landscape ecology (Scherr and McNeely, 2008). This approach can be widened to take into account non-rural services within the context of regional planning (McHarg, 1969) and even arts proposals (Firbank et al., 2009). Ecoagriculture raises the possibility of radical changes to landscapes and the potential of creating new perceptions of landscape quality, informed by the range of ecosystem services delivered.

Such changes in approach may be triggered by considerable increases in the price of fossil fuels, which would also raise the prices of inorganic fertilisers. The regional specialisation of UK agriculture followed the introduction of inorganic fertilisers and the replacement of horses by machinery; this process has been predicated on cheap nutrients and cheap energy. If energy, nutrient and transport costs were to increase substantially, the result may be a return to mixed farming, albeit of a new kind, perhaps involving large-scale mixed units, combining animal production, fodder crops and crop residues to feed the animals, arable crops to use the slurries and manures and perhaps an anaerobic digestor plant to use food wastes for energy.

5. Conclusions

Enclosed Farmland has been, and remains, a vital habitat in terms of food production and its provision of landscape, biodiversity and other cultural benefits. Production landscapes also impose important disbenefits to the UK, in terms of emissions of GHG, diffuse water pollution and losses to biodiversity. Greater demand is expected of multiple ecosystem services including food and bioenergy production, GHG emission mitigation and cultural services. There is no single way of delivering multifunctional land use; variation between soils, climate, accessibility and existing land use determine that it is best to promote a diversity of farming systems and allocation of land, at a range of spatial scales, to deliver different ecosystem services. But, there are major challenges and knowledge gaps about how such integrated land use could be determined and delivered (see also Harris, 2007).

The first is that there are weaknesses in the research base. Our understanding of the relationships between biodiversity (including soil biodiversity) and ecosystem function (including food production) is improving but still not clear (e.g. Loreau, 2010). Nor is it clear what level of functional redundancy exists across different taxa for regulating and other services. The interactions, both positive and negative, between different ecosystem services in response to particular management strategies are not well understood.

A second challenge concerns governance. Scales of service delivery do not always coincide with the scales of land ownership (Scherr and McNeely, 2008). For example, diffuse pollution is best managed at the catchment scale, biodiversity conservation using the spatial arrangements of habitats is best delivered at the landscape scale, but agricultural production is managed at the scale of the appropriate economic unit, usually the whole farm.

The third challenge is to influence land management decisions. There is a clear need to integrate ecosystem service delivery into the business models of agricultural enterprise. This is far from trivial, given that drivers of decision making are becoming more complex (e.g. unstable markets, extreme weather events, the desire for biodiversity conservation, the need for pest control, nutrient cycling and the control of diffuse pollution, etc.). Such complexity is currently likely to be managed more efficiently by larger and/or more specialised enterprises, especially when they are able to access and adopt information on best practice. There will be new requirements for knowledge exchange. Some farms would start from a low base, for example an estimated 32% of UK holdings do not test the nutrient content of soil (Defra, 2010a) despite the financial costs and environmental concerns over excessive nutrient inputs.

The fourth challenge concerns the availability of tools to create the enabling environment for multiple service provision. Currently, negative 'external' impacts of agricultural production on regulating services are controlled by regulations, often transposed from European directives, including the Water Framework Directive, Pesticides Directive, Habitats Directive, Nitrates Directive, and Landscape Directive, and through the Common Agricultural Policy (CAP). More pro-active delivery of cultural services are supported largely through markets and incentives, the latter mainly through the so-called 'Pillar 2' of the CAP, in the form of agri-environment schemes. In the UK, there are two well-developed kinds of market support for ecosystem services other than food and energy production. One is direct payment, whether for the purchase of land by water companies or for holiday accommodation in the countryside, for which there are mature markets, or for carbon sequestration, the market for which is in its infancy. Another support is to seek increased market share by adding value to food items. For example, Conservation Grade, the LEAF marque and organic production all have mechanisms for incorporating environmental objectives into production and marketing of food. The promotion of products with added environmental value by supermarket chains is enabling their market penetration (Anderson and Firbank, 2009).

Pro-active management to enhance biodiversity and cultural services is largely supported by agri-environment and similar incentive schemes. Management for biodiversity appears to work best when focused on designated sites and/or targeted actions for particular range-restricted populations (Aebischer et al., 2000; Kleijn and Sutherland, 2003; Wilson et al., 2009). For example, in the UK, targeted agri-environment measures resulted in increases in breeding cirl buntings of 133% between 1993 and 2009, and in Scottish corncrakes of 181% between 1994 and 2008 (McCracken and Midgley, 2010).

Such approaches can be extended to other ecosystem services. However, establishing the appropriate rates of payments is far from easy. While work is ongoing to try to capture the economic value of bundles of ecosystem services (TEEB, 2010; Bateman et al., 2011), it is clear from the UKNEA that there is much more research needed (UKNEA, 2011). The values of such benefits can change rapidly, and are perceived very differently by different members of society, making it difficult to value long term needs as opposed to short term gains (Bennett et al., 2009).

Discussions are now underway on the reform of the CAP, with aims that include maintaining capacity for food production, reducing environmental harm, delivering environmental benefits and addressing climate change (EC, 2010). There is clearly scope to develop policies that are better aligned to improving the delivery of multiple ecosystem services from farmland. However if the proposals current at the time of writing (EC, 2011) are implemented, expenditure on the so-called Pillar 2 of the CAP would decline in real terms by about 7% over the period 2014–2020 (Baldock, 2011). Such reductions are likely to constrain the CAP's capacity to reward farmers for the ecosystem services they provide, for which there is currently no mature market and which appears to be substantially under-resourced already (Cao et al., 2009). The Commission's current proposals indicate that in future 30% of direct payments to farmers (from the so-called Pillar 1 of the CAP) will be made contingent on a range of environmentally sound practices, going beyond cross-compliance. There is as yet no detail of how these greening measures will be implemented, but it seems unlikely that they will support optimised land management for ecosystem service delivery, given that they are likely to be blanket measures with little targeting or tailoring.

Assuming that the management of Enclosed Farmland does evolve to enhance the productivity of multiple ecosystem services, will the productivity still be enough to meet demand? In terms of food production, much depends on global demand, impacts of climate change and whether the trend to increased meat diets continues. Within the UK, much depends on how well food wastes, consumer demand and nutrients are managed, and the extent to which food is produced outwith Enclosed Farmland, not least in urban and glasshouse developments.

To conclude, more multifunctional management of Enclosed Farmland is required to meet rising demand for ecosystem services and it could be delivered through the creation of new patterns of knowledge generation and exchange, market mechanisms, incentives and regulation. A better understanding of the generation and flows of ecosystem services, and their interactions, is critical to designing these new patterns; a better understanding of the economics and governance of ecosystem services is essential if they are then to be achieved on the ground.

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