Summary of evidence: Land management

1 General introduction

This summary sets out Natural England's assessment of the evidence relating to land management. It provides a statement of the current evidence base, presenting:

- what we know (with supporting data and key references);
- areas that are subject to active research and debate; and
- what we do not yet know from the evidence base.

It also provides information on Natural England research and key external research programmes to show how we are seeking to fill gaps.

This summary forms part of a suite of summaries covering all of Natural England's remit. The summaries are not systematic reviews, but enable us to identify areas where the evidence is absent, or complex, conflicting and/or contested. These summaries are for both internal and external use and will be regularly updated as new evidence emerges and more detailed reviews are completed.

2 Introduction to land management

The term 'Land Management' is used here to describe the various ways in which land that is essentially undeveloped is managed. Agriculture is the most important and widespread use of undeveloped land, covering about 70% of the land surface of England. Woodland, with varying degrees of woodland management, comes next at 10%. Other significant forms of land management (often overlapping) include military training, recreational use, game management, water resources and nature conservation. This document is concerned with the evidence relating to the interactions between these forms of land management, the natural environment and our cultural heritage.

The evidence is presented under the following headings:

- Historical context.
- Lowland land management.
- Land management and the historic environment and landscapes.
- Woodland management (to be added in a later edition).
- Upland land management.
- Land management and water quality.
- Land management and atmospheric pollution.
- Agri-environment scheme design, targeting and delivery.
- The wider benefits of land management changes delivered through agri-environment schemes.

Summary of evidence: Land management EIN008

First edition 10 March 2015

3 Historical context – The impact of land management practices on the natural environment

What we know:

3.1 The application of science and technology to farming has dramatically increased yields from most farming systems since the 1940s. UK total agricultural output (weighted by value) rose by almost 180 per cent between the mid-1950s and a peak in the mid-1980s (Angus *et al.* 2008). Average yields of wheat in England increased from around 2.5 tonnes/ha in 1945 to 7.8 tonnes/ha in 2011 (Defra 2011a). Milk yields per cow doubled during the period 1960–2000 and the UK sheep flock peaked in 1992 at 44 million (Angus *et al.* 2008). This increase was the result of a number of changes, including mechanisation, use of artificial fertilisers, increasingly sophisticated pesticides and advances in plant and animal breeding. The need for labour for farm and environmental management declined dramatically during the period. Agricultural employment fell from 876,000 FTE (full time equivalents) in 1960 to 242,000 FTE in 2003 (Defra, 2004a). This process, often referred to as 'agricultural intensification', is more than just about increased levels of inputs. Mechanisation has allowed crops and livestock to be farmed on a much bigger scale. Along with the use of agro-chemicals, this permitted greatly simplified patterns of cropping and encouraged a trend towards much more specialised agricultural enterprises.

3.2 In recent years the increase in yields has tended to level off, with wheat yields, for example, increasing by only 4% in the past 15 years (Defra 2011a), but changes aimed at reducing costs and making farming more efficient have continued. These changes have included reductions in the levels of some inputs, but also a continuing polarisation of farming businesses including larger and more specialised farm enterprises and smaller diversified enterprises that add value, as exemplified by the rise of 'block cropping' (the practice of co-locating fields of particular crops, to minimise the need to move large machinery across the farm).

3.3 Historically these changes in farming were a major cause of the observed decline in biodiversity, and of landscape change. Biodiversity declined both because of the outright loss of many areas of semi-natural habitat, as these were converted to modern agricultural use, and because of changes to the nature of the farmed land itself, which reduced the range of species that can survive on it. The extent of historical habitat losses was reviewed by English Nature (Townshend, Stace & Radley 2004). The most dramatic example of outright habitat loss was that of lowland unimproved grasslands, which underwent a 97% reduction in area between 1930 and 1984 in England and Wales (Fuller 1987). Specialist farmland birds are used as an indicator of the wider biodiversity of farmland; an index tracking the populations of 12 species showed a dramatic decline between 1970 and the late 1990s (Defra 2013a).

3.4 The decline in biodiversity was paralleled by dramatic losses of historical environment features such as ridge and furrow grassland (Hall 2001), and very large scale changes to agricultural landscapes, typified by the dramatic reduction in the length of hedgerow in England in the decades following the Second World War (Macdonald and Johnson, 2000). From the 1940s until 1999, agriculture has been the cause of the outright destruction of 80% of ridge and furrow in the East Midlands. A further 4% was lost between 1999 and 2011 (Catchpole *et al.* 2012). More than half of our nationally important archaeological sites are at risk from agriculture - particularly arable cultivation (Catchpole *et al.* 2012). In addition, traditional farm buildings are the single largest category of 'at risk' building on local authority risk registers (Gaskell, 2009) and 45.8% of historic parkland extant in 1918 has been lost, with agricultural intensification being one of the major causes of degradation (Natural England 2009).

3.5 Strengthened environmental regulation, in combination with environmental land management payments, was introduced in the 1980s. The 1981 Wildlife and Countryside Act strengthened a level of control over the agricultural and forestry management of SSSIs for the first time, and the level of statutory protection has been increased, both by successive amendments to domestic legislation and by the EU Habitats and Birds Directives. Although the European Union has made relatively small sums available for its dedicated environmental programmes, it has sought to secure its environmental objectives through the integration of those objectives into its mainstream funds. This has secured significant funding for the environment. The success of this approach (known as ‘mainstreaming’) has varied across the funds, but CAP Rural Development Programmes now include significant financial support for environmental land management through agri-environmental and forestry schemes.

3.6 Agri-environment schemes, first introduced in 1985 and progressively expanded since, have complemented designations by providing a means of rewarding the positive management of statutory sites and have also provided a mechanism for rewarding farmers for the positive management of landscapes, historic environment features and undesignated habitats in the wider countryside.

3.7 These environmental measures made a major contribution to the conservation of biodiversity, landscapes and the historic environment. Working together these mechanisms have achieved considerable success. A review of the achievements of the English ‘Classic Schemes’ concluded that the Environmentally Sensitive Areas (ESAs) had at least partially succeeded in maintaining the wildlife value of the areas they covered, maintaining and enhancing the landscape values and maintaining the values of the historic environment. Countryside Stewardship was found to have had some notable successes in reversing the declines of localised bird species, including the cirl bunting and stone curlew. In the lowlands, most agreements also seemed to be on course to maintain and enhance wildlife and landscape value (Ecoscope 2003).

3.8 In more recent years many of the adverse impacts of agriculture have been mitigated, and there have been areas of environmental improvement, though some indicators of farmland biodiversity continue to decline. Outright habitat loss has slowed, and in some cases reversed. Major efforts have been made to maintain, restore and even recreate semi-natural habitats and these have met with some success (see for example Kirkham *et al.* 2006).

3.9 Reforms to the Common Agricultural Policy, particularly the removal of production-linked subsidies, have also reduced the pressure on farmers to maximise, rather than optimise production. The impact of this and other factors (for example Foot and Mouth Disease) has been particularly marked in the livestock sector, where the population of sheep in England fell by 26% between 2000 and 2010 (Defra 2010c).

3.10 In 2014, Defra reviewed the changes to indicators relevant to the state of biodiversity in England since 2000 (Defra 2014c), a number of which are relevant to farmed land. Whilst the indicators relating to water quality showed some improvement, those relating to the plants and animals that directly depend on farmed land and the farmland habitats themselves showed a more mixed picture. Amongst species groups, bat populations are increasing but the farmland bird index shows no sign of recovery. The majority of butterfly species have continued to decline because of habitat deterioration resulting from a combination of neglect and intensification (Fox *et al.* 2011). The Countryside Survey

(Smart *et al.* 2010) has shown evidence of a continued decline in plant species diversity in the more botanically-interesting neutral grasslands and in boundary habitats, but the plant diversity of arable and horticultural farming systems has improved.

4 Lowland land management and biodiversity

4.1 This section focuses specifically on the interaction between land management practices and biodiversity. A separate summary of evidence for biodiversity is available in this series.

What we know:

Arable farming systems

4.2 A range of arable options was incorporated in the design of Environmental Stewardship. Most of these use the principle of 'land sparing' where small areas of land are taken out of normal production and managed specifically for environmental purposes. Much of the experience gained was summarised in Boatman *et al.* 2007.

4.3 Arable margins sown with nectar, pollen and native wild flower mixes attract greater numbers of bumblebees than cropped, grassy or naturally regenerated margins (systematic review, Dicks, Showler & Sutherland 2010). The SAFFIE Project (Clarke *et al.* 2007) and the Hillesden Project (Hinsley *et al.* 2010, Heard *et al.* in press) have between them provided a lot of information on the management of buffer strips for biodiversity.

4.4 Land-based schemes are effective in maintaining higher densities of farmland bird species, especially during winter periods, compared to conventionally cropped fields (systematic review, Roberts & Pullin 2007). The focus on farmland birds arose largely because the availability of robust population data over a long period of time led to their choice as an indicator for the wider biodiversity of farmland. Not all species will benefit from management designed primarily to benefit farmland birds, but there is some evidence for spin-off benefits for other species (MacDonald *et al.* 2012).

4.5 There is a weakness with the provision of habitat for farmland birds, and there has been the late winter 'hungry gap', after seed sources provided by sown plots are exhausted (BTO 2007). An extended stubble option and a supplementary feeding option have been introduced to help tackle this problem for arable farmland. Applying this approach to intensive grasslands took longer, but much of the necessary underpinning research has now been done (See for example Buckingham *et al.* 2011; Peach *et al.* 2007; Pywell *et al.* 2007). A new management option has been developed for intensive grasslands which allows small areas of ryegrass to seed and so provide a food source.

4.6 There is good knowledge of the scale of habitat creation needed to sustain populations of farmland birds (Winspear *et al.* 2010) and more evidence is emerging, especially in relation to winter bird food (Baker *et al.* 2012). Similar information is available for a few other species, including the brown hare (Game & Wildlife Conservation Trust 2010). The systematic review of bee conservation (Dicks, Showler & Sutherland 2010) found in one large trial that the average abundance of long-tongued bumblebees on field margins was positively correlated with the number of 'pollen and nectar' agri-environment agreements within a 10 km grid square.

Extensive grassland systems

4.7 There is a good understanding of the impact of soil pH, nutrient status, fertilisers and manures on species-rich grassland (Kirkham *et al.* 2014) and the management needed to maintain, restore and re-create most types of species-rich grassland. This knowledge has served to highlight how difficult this management can often be to achieve in practice. Nevertheless, recent evidence (Stevens & Wilson 2012; Hewins 2011) has demonstrated that it is possible to create species-rich grassland swards that fall within the definition of grassland BAP priority habitat under Higher Level Stewardship agreements. Successful re-creation and restoration is particularly dependent on soil conditions and seed supply (Pywell *et al.* 2007).

4.8 There are grazing management and sward height prescriptions that strike a balance between maintaining species-rich swards and good livestock performance on species-rich lowland neutral grassland (Defra 2006; Stewart & Pullin 2006). We are also learning how to manage grazing to increase abundance and diversity of invertebrates, and hence food for declining bird species (Peach *et al.* 2007).

4.9 Introducing hay-cutting for one year or more can 'kick-start' restoration of botanical diversity, control injurious weeds and offer the opportunity to introduce missing species, and can be a better management regime for species rich grasslands than grazing every year (Defra (h)).

4.10 There are grazing management and sward height prescriptions to increase abundance and diversity of invertebrates, **and hence food for declining bird species, in semi-improved relatively species-poor grassland** (Peach *et al.* 2007; Buckingham *et al.* 2011). This knowledge has resulted in the development of the lenient grazing supplement in the new Countryside Stewardship scheme.

4.11 The management requirements for species-rich flood plain grasslands (MG4 and MG8 and related vegetation) are well known (Gowing 2004), and work to produce a technical management handbook is well advanced. Recent work (Smart *et al.* 2014; Bolton *et al.* 2007; Malcolm *et al.* 2009) has clarified the habitat management and predator control regimes necessary to improve the conservation of breeding wader populations on wet grasslands. The management requirements of other semi-natural grasslands is well-known although further research on aspects of grazing management (timing, advantages/disadvantages of different species and breeds) would be beneficial.

4.12 Without current regulatory, advisory and incentive mechanisms, biodiversity losses would have been much greater. Pinches & Rimes (2007) compared the condition of species rich lowland grasslands on statutory and non-statutory sites across the UK and found that, whilst many designated and undesignated sites were in unfavourable condition, the percentage of undesignated sites in unfavourable condition was consistently higher. Other studies have shown that grassland inventory sites recorded in the 1980s have experienced a very high rate of attrition when not subject to either designation or agri-environmental management (see for example Hewins *et al.* 2005).

4.13 Creation and restoration of species-rich grassland has been one of the major areas of agri-environment spend. Higher Level Stewardship (HLS) has been successfully used to re-create species-rich grassland communities (Hewins 2011; Stevens & Wilson 2012). Several research projects relating to this have just concluded and should enable better guidance on defining the restorability of candidate sites (Defra (a) in prep) and the trajectory and timescale required to reach BAP Priority Habitat standard (Defra (b) in prep). We now know that restoration of the most specialised and demanding plant species can be successfully achieved, at least in calcareous grasslands (Defra (c) in prep).

Hedgerows

4.14 Entry Level Stewardship (ELS) has achieved a marked shift in hedgerow management, with a significant decline in the proportion of hedges in England that are cut every year (Britt *et al.* 2011). However, whilst ELS payments may have altered farmer's hedgerow management practices, they have had limited success in changing their attitudes to and beliefs about hedgerow management, which must call into question the long term sustainability of the management changes (Britt *et al.* 2011). Numbers of hedgerow trees are declining (Forest Research 2009), but they are important for the landscape-scale conservation of key species, including moth species and the bats that feed on them.

Lowland wetlands

4.15 Wetlands and other freshwater ecosystems are important globally for provisioning, regulating and supporting ecosystem services, as well as having a significant cultural value (Maltby *et al.* 2011). Wetlands are also particularly important for their record of our archaeological heritage, and wetland losses have had a severe effect on that cultural service – for example, up to 50% of the archaeological sites that existed in peatlands in England in 1950 were lost by 2000 (van de Noort *et al.* 2001). The extent of ecosystem services provided by most freshwaters and wetlands has become more restricted in recent years (Maltby *et al.* 2011). Restoration of ecosystem functioning is likely to deliver generally positive benefits to the full range of provisioning, regulatory, cultural and supporting ecosystem services, (Everard & Kataria 2010).

4.16 The management requirements of wetlands are well known (McBride *et al.* 2011), but management is often highly resource intensive, especially where the regular removal of biomass is needed. We have a much improved knowledge of the water regime requirements of specific types of wetlands of particular conservation importance (Wheeler *et al.* 2009). The creation of reedbeds has been very successful as demonstrated by the continuing rise in the numbers of breeding bittern in England (Brown *et al.* 2012).

4.17 Land management practices operating at wetland catchment scale need to be coordinated in order to achieve the improvements in water quantity and quality that are required by low nutrient wetlands (McBride *et al.* 2011).

Lowland heathland

4.18 A great deal is known about how to manage heathland for the plant communities and the key species that they support - these require a diverse vegetation structure, including patches of bare ground (Symes & Day 2003; Webb *et al.* 2010). The importance of patch size and connectivity is also better understood than for many other habitats (Webb & Thomas 1994; Webb 1989). The potential for heathland re-creation, and the implications of heathland creation on the historic environment and soils are well known (Hawley *et al.* 2008), as are the limitations on re-creation, particularly from farmland (Pywell *et al.* 1994; 1995b; Walker *et al.* 2004, 2007). There is evidence that grazing animals can produce a microstructural diversity impossible to achieve mechanically (Lake *et al.* 2001). Comparative research has shown the grazed areas have greater botanical species richness than areas mown or recovering from burns (Pywell *et al.* 1995a). The former had a higher incidence of low-growing and small forbs and grasses. Overgrazing, on the other hand, can be damaging but even low levels of grazing can have negative impacts on some species, e.g. reptiles (Lake *et al.* 2001). Grazing generally involves fencing and this can cause conflict, especially on commons with high levels of public access.

Wood-pasture and parkland habitats

4.19 Wood-pasture and parkland is a priority habitat which supports 41% of the priority species associated with woodland (Webb *et al.* 2010). The conditions created by wood decay fungi in veteran trees provide a mosaic of micro-habitats that support rare saproxylic invertebrates, and nearly 11% of the saproxylic beetles found in veteran trees are considered threatened in Europe, with a further 13% considered near threatened. The ecological continuity provided by the wood decay inside the veteran trees is not found in any other habitats. The value of 'non-woodland' trees in the landscape in providing connectivity between sites for different species is poorly understood. A separate summary of evidence is available for wood-pasture and parkland in this series.

Coastal habitats

4.20 The Land Use summary of evidence in this series contains a wider range of information about coastal management issues, primarily relating to flood and erosion risk management. Climate change is also a major consideration for coastal habitats and more detail is provided in the relevant summary.

4.21 Diffuse air and water pollution (often from land management practices or intensive agriculture elsewhere) has significant impacts on coastal and marine environments. Sand dunes in particular are negatively affected by nitrogen deposition. To mitigate the impacts, grazing or other management is often recommended; however, many dunes have suffered from the loss of historical grazing. Eutrophication of the estuarine environment by diffuse sources is also an issue - see the Marine summary of evidence in this series.

4.22 A key interaction between coastal environments and land management is the impact of land claim from intertidal areas and taking action to restore functionally of the coastal flood plain. For many years, even as recently as the 1980s, intertidal areas have been drained and enclosed, as part of the drive for greater production. There are examples where these embanked areas are now being restored to reinstate tidal inundation and create habitat by managed realignment (e.g. Badley & Allcom 2006).

Soils

4.23 A separate summary of evidence for soils is being produced.

4.24 We know that soil biota have been drastically modified by modern agricultural practices, the use of agro-chemicals, deeper and more frequent cultivation and simplified crop rotations. The comprehensive summary of the long term Defra-funded research programme (Robinson *et al.* 2008) sets out what is known about the ecosystem services provided by soils and how these can be affected by the ways in which soils are managed. This has also made it clear that there are major continuing uncertainties, and the report suggests a number of priorities for further research.

What we don't know:

4.25 Information on the current quality and even extent of many wetland habitats remains inadequate. Current work on existing inventories will help, but an urgent priority is further survey for key wetland habitats in order to plan more effective targeting for restoration and creation of new habitats.

4.26 The way in which wetland restoration can contribute to improvements in a wide range of ecosystem services, including: the role of wetland restoration and management in greenhouse gas; use of wetland treatment systems for removal of nutrients from effluents/runoff; how different freshwater habitat types, (quality, size, and connectivity) affect provision of ecosystem services; and practical examples of integrated catchment management in lowland systems.

4.27 When and what type of grazing is necessary for achieving lowland heathland favourable condition. Conservation-based heathland management has generally favoured maintaining or restoring appropriate, extensive grazing as the best way of maintaining a diverse heathland vegetation (Lake, Bullock & Hartley 2001). A systematic review of the comparative merits of grazing, burning and no management (Newton *et al.* 2009) concluded that there is limited empirical evidence regarding the relative impacts of burning, grazing and cutting on lowland heath and much unexplained variation in the outcome. The authors concluded that further research and long-term monitoring regarding the effects of heathland management was urgently required.

4.28 How to reduce the cost and carbon footprint of habitat management. For wetlands, heathlands and other habitats which are now managed primarily outside mainstream farming, environmental land management often involves periodic removal of large quantities of biomass. There is a need to find both more economical ways of doing this, and ways of making use of the products instead of burning them or sending them to landfill, which results in carbon emissions (Alonso *et al.* 2012). Biomass for compost, energy and as a feedstock may offer new markets. Pilots have also taken place to find use for heathland by-products (Little 2011). Feasibility studies into use of wetland arisings have been undertaken in the UK, e.g. ELP & Ash (2010).

4.29 Whether it is possible to deliver measurable improvements in agricultural productivity as a result of management to enhance soil biota.

4.30 How the ecosystem services provided by soils are affected by changes in land use and land management.

4.31 How to mitigate the impacts of nitrogen deposition in coastal habitats using grazing. Grazing can slow down the impacts of deposition (Plassmann *et al.* 2010). Some work under HLS has taken place but more needs to be done to understand the seasonality and levels of grazing required to reverse over-stabilisation and recover more of the early stage dune habitats.

4.32 How grazing affects the species use of saltmarshes. Grazing management of coastal habitats is generally considered as good practice, but some species may suffer. For example, grazing resulted in serious declines in redshank breeding species (Norris *et al.* 1997; Malpas *et al.* 2011, Malpas *et al.* in preparation) and some invertebrates (Ford *et al.* 2013). The saltmarsh grazing survey carried out in 2013 aims to provide information on how conservation management guidelines could be improved.

4.33 How to maintain/reinstate coastal grazing. Grazing patterns have changed with the changes in farming systems, with the loss of seasonal grazing on dunes, saltmarshes and cliff slopes, using upland or other livestock (often hardy traditional breeds), and the lack of suitable livestock. There is a need to understand how the infrastructure required to support grazing in coastal habitats can be provided so that grazing is sustained in the places where it is needed.

5 Land management and the historic environment and landscapes

5.1 This section focuses specifically on the interaction between land management practice and landscape character and the historic environment.

What we know:

5.2 We understand the effects of different cultivation regimes and some habitat restoration techniques on above and below-ground historic features. Based on the outcomes of the COSMIC and TRIALs work undertaken as part of Defra and English Heritage R&D work, we have a means of assessing the risk of cultivation damage to individual monuments, based on site specific factors (Oxford Archaeology 2006; Oxford Archaeology *et al.* 2009). Work has also provided information on key issues around heathland creation and management (Alonso *et al.* 2009) and we have some information on the impact of different types of vegetation on historic environment features.

5.3 There is concern about the potential loss of protection for historic environment features as a result of more intensive cultivation, changes to incentive schemes and a lack of protection through Environmental Impact Assessment regulation. Anecdotal evidence suggests an increasing loss of ridge and furrow and earthwork remains in grassland as more cultivation takes place in historically predominantly pastoral areas. Recent research carried out for Natural England suggests that many land managers intend retaining grassland reverted from arable even after agreements have expired (ADAS 2014). To date there is little information as to what actually happens.

5.4 For the historic environment, Agri-Environment Schemes (AES) are a key driver in improving the condition of historic environment features. English Heritage time series data based on the 1,515 Scheduled monuments in farmland in the East Midlands shows a reduction in risk for those in AES, with a 78% improvement in condition between 2005-7 directly attributable to Environmental Stewardship (ES) management (Boatman *et al.* 2008). Both undesignated and designated monuments within ES have increased protection to those in the older Classic schemes: the multi-objective emphasis of the new schemes means that, even if an option does not lead to a land use change, the more positive management attributed to ES reduces monument vulnerability and reduces risk (English Heritage 2009). The need for consistent, accessible information on the extent, distribution and condition of unscheduled historic monuments has been addressed through the SHINE project (Defra 2013b)

5.5 How to measure the cumulative impact of agri-environmental and other interventions on landscape quality and character. A major research project has recently defined a methodology to enable monitoring and reporting of the direct and cumulative impacts of Environmental Stewardship on the maintenance and enhancement of landscape character and quality (Defra 2013c). A monitoring programme using this methodology was started in 2013 (Defra (d)).

What we don't know:

5.6 We lack data on the continuing rates of loss and damage to unscheduled monuments caused by agriculture.

5.7 We lack a sound means of determining how to effectively use Historic Landscape characterisation to enhance the targeting of options for protection and enhancement of the historic landscape.

6 Woodland management

6.1 To be added in the next edition.

7 Upland land management

7.1 Natural England undertook a comprehensive Uplands Evidence Review in 2012-13 (Natural England 2013) which involved input from a number of stakeholders. This section broadly summarises findings from the five specific areas under review:

- The impact of tracks on the integrity and hydrological function of blanket peat.
- Restoration of degraded blanket bog.
- The effects of managed burning on upland peatland biodiversity, carbon and water.
- Upland hay meadows: what management regimes maintain the diversity of meadow flora and populations of breeding birds?
- Impacts of moorland grazing and stocking rates.

What we know:

7.2 Many upland habitats are in poor condition. Natural England statistics from 2013 showed that only 13% of blanket bog on SSSIs was in favourable condition (Defra 2014c). We also know a great deal about the causes of decline in upland habitats, and an increasing amount about the management needed to maintain and restore key upland habitats and some ecosystem services.

7.3 Upland habitats are important not only for biodiversity but also for a range of ecosystem services, including food and timber production, access and recreation, the storage and sequestration of carbon, the provision of good quality drinking water and the mitigation of flooding. The majority of timber production in the uplands is in Kielder and the South Lakes, with only relatively small areas in the other upland areas of England (see MAGIC website **www.magic.gov.uk**).

7.4 There are both conflicts and synergies between the different ecosystem services that mountains, moorland and heath provide (Van der Wal *et al.* 2011). There are many synergies between the management needed to restore biodiversity, protect carbon stocks and improve water quality and quantity. However, there are also potential conflicts, particularly between the management that optimises delivery of these services and that which optimises the provision of other services, particularly the production of food, shooting and energy.

7.5 Impact of grazing on upland heathland. Grazing has a direct impact on the composition and condition of habitats. There is an association between sheep stocking rates at the landscape scale and the extent and condition of dwarf-shrub habitats (e.g. Anderson & Yalden 1981). Agri-environment agreements covering moorland have generally halted deterioration of heathland and blanket bog habitats, and there is limited evidence of improvements in condition, but heathland habitat expansion is generally slow or lacking (Ecoscope 2003; Boatman *et al.* 2008; Critchley *et al.* 2008), in some cases related to increases in non-desirable graminoids such as Molinia (Critchley *et al.* 2008). Annual average grazing levels of around 0.1 Livestock Unit (approximately I ewe)/ha/year) or lower gives the greatest likelihood of improving the condition of heathland habitat (Hulme *et al.* 2002; Pakeman *et al.* 2003) which accords with agri-environment monitoring findings that the higher restoration tiers are likely to be most successful.

7.6 Grazing and restoration of upland heathland. Significantly lower stocking rates are required for the restoration of habitats with lower annual growth and productivity, but exact stocking rates are influenced by a complex interaction of extent and distribution of vegetation types available to graze, topography, climate and livestock management systems. The overall impact of a given stocking rate is influenced by the size and distribution of grass patches (e.g. Clark *et al.* 1995; Oom *et al.* 2008, 2010; Palmer *et al.* 2003; Sibbald *et al.* 2008). Grazing preferences also vary seasonally, influencing the impacts of different timing of grazing (Welch 1998; Hulme *et al.* 2002; Gardner *et al.* 2002). The annual productivity of different vegetation types varies between locations and years (Milne *et al.* 2002). Sheep display greater fine-scale selectivity of diet than cattle, leading to different grazing outcomes (Grant *et al.* 1985, 1987; Hodgson *et al.* 1991; Fraser *et al.* 2009). Cattle are more likely to graze mat grass and purple moor-grass that sheep avoid or graze less frequently (similar references to above). Grazing affects the structure of moorland food webs, i.e. invertebrate and bird assemblages, through its influence on vegetation composition and structure (Pearce-Higgins & Grant, 2006; Dennis *et al.* 1997, 2001, 2002, 2008; Littlewood 2008). Invertebrate biomass increases with grazing reduction or removal. However grazing intensity (through effect on structure and timing) will affect the functional groups present. Low intensity, mixed (livestock type) grazing is likely to have general biodiversity benefits. Atmospheric nitrogen deposition is also likely to influence the effects of grazing (Hartley & Mitchell 2005; Hartley 1997; Van der Wal *et al.* 2003; Gordon *et al.* 2001).

7.7 The impact of vehicle tracks on blanket peat. Tracks alter the structural integrity and the hydrological system of blanket peat at either surface or sub-surface level. Artificial drainage associated with tracks can focus water upon areas of weakness leading to instability, result in the settlement of peat and lead to drying and erosion of associated peat areas. The types of vehicle, loading and usage influences the impact of unmade tracks upon the structural integrity and hydrology of blanket peat. Once initiated, these processes were found to be ongoing and in some cases, irreversible (Grace *et al.* 2013).

7.8 The sustainable nutrient and spring grazing regime for a species-rich northern hay meadow. Applications of farmyard manure (FYM) of up to 12 tonnes/ha/year will maintain current diversity on meadows with a history of this rate of application (Kirkham *et al.* 2014). FYM applications of 6 tonnes/ha/year or less should be used to enhance or restore characteristic flora. To retain botanical quality, livestock should be excluded from the hay meadow no later than 15th May, and the average sward height should be > 5 cm in the spring-grazing period. (Smith *et al.* 2012).

Areas that are subject to active research and debate:

7.9 The evidence for the ecosystem service benefits of peatland management; including grip blocking, the restoration of degraded peatlands, rotational burning and wetland restoration. There is active investigation of a number of ecosystem service benefits, including a reduction in greenhouse gas, better water resource management, improved water quality and the restoration of biodiversity. The IUCN UK Peatland Programme's Commission of Inquiry on Peatlands (Bain *et al.* 2011) has identified actual and potential benefits across a range of ecosystem services, including the conservation of biodiversity, water management and reduced greenhouse gas emissions (Worrall *et al.* 2010). The evidence on the hydrological and greenhouse gas benefits of grip blocking in particular has also been reviewed for the Moors for the Future Project (Holden 2009). Defra-funded research is also underway in this area (Defra (e)). The impact of grip blocking on greenhouse gas emissions is particularly difficult to quantify. The re-wetting of the peat and the blocking of drainage grips reduces levels of dissolved organic carbon in run-off water and the production of atmospheric carbon dioxide, but in the short-term, it increases the emissions of methane (Holden, 2005, 2006; Holden *et al.* 2004, 2006 &

2007). Both the IUCN and the Holden reviews agree that more work is needed to accurately quantify the potential greenhouse gas and water quality benefits. Defra is currently funding a major research programme to determine whether the net impact of grip blocking and peatland re-wetting is to reduce or increase greenhouse gas emissions (Defra).

7.10 Whilst there is good evidence that fire encourages the growth of vascular plants, particularly graminoids and heather, more work is needed on the long-term trajectories for the ecological character of areas under differing burning regimes and changing climatic conditions (Lindsay 2010). In particular this review concluded that the relationship between fire and Sphagnum should be given specific, detailed attention and is the subject of a new PhD CASE studentship at Leeds University in collaboration with Natural England.

7.11 How to restore blanket bog to favourable condition. Agri-environment schemes have had only limited success in restoring upland habitats to favourable condition and there is a need for additional evidence to guide management (Shepherd *et al.* 2013). A systematic review of the effect of burning of dry upland heath on vegetation diversity (Stewart, Coles & Pullin 2004b) found that burning old stands can reduce diversity, but it concluded that more research was required to provide evidence concerning site-specific factors. Research in relation to the restoration of blanket bogs is in progress, and a major project (BD5104) has recently been let (Defra (e)). The Moors for the Future Partnership carried out a major review of the current status of Sphagnum in the blanket bogs of the Peak District and the potential for its restoration (Carroll *et al.* 2009). It is also developing techniques for encouraging the re-growth of Sphagnum, which it is hoped will help re-start peat accumulation (see Bain *et al.* 2011). Widespread restoration of blanket bog does represent a considerable challenge. Some blanket bogs have been very severely damaged, and climate change raises the possibility that some may in future be outside the climatic limits for active blanket bog, though the science behind this remains uncertain.

7.12 The management needed to maintain the biodiversity value of northern hay meadows within agricultural systems. A great deal is known about the conservation management needs of northern hay meadows (Jefferson 2005; Smith 2010), but despite this, there is evidence of widespread deterioration (Pinches *et al.* 2013). Considerable research has been undertaken on the management of these meadows, focusing mainly on nutrient management but also on shut-up times (Defra 2012).

7.13 Alternatives for bracken management in response to reduced pesticide availability. Bracken management at present relies heavily on chemical control using the herbicide Asulam but, with its withdrawal through EU legislation (EU SU Directive 2010), we need to assess the effectiveness of alternative physical control methods (Stewart, Tyler & Pullin 2005). Current Natural England research is looking at alternative chemical control methods for bracken, and, in collaboration with English Heritage, at the efficacy of non-chemical bracken control, particularly in protecting the historic environment.

What we don't know:

7.14 How sustainable intensification and a better environment could be achieved in the uplands. In upland areas, where much of the farmed area can be of high biodiversity value and/or important for the safeguarding of other ecosystem services, a 'land sharing' approach is needed, but UK experience to date has been that increased agricultural production in the uplands is almost inevitably associated with losses in a variety of other ecosystem services. There have been very innovative attempts to combine intensification and environmental benefits in other countries (e.g. Anon 2008), but it remains to be seen whether this experience could be directly transferred to the UK.

7.15 We still have a poor understanding of the spatial dynamics of grazing in the uplands. Our understanding of what determines the ranging and grazing behaviour of sheep on moorland is poor. Most of the behavioural studies of grazing sheep have been carried out in Scotland, and it is not clear whether there is an effect across breeds, nor whether the particular stratification system operating in England has an effect (Martin *et al.* 2013).

7.16 We do not know how best to manipulate grazing livestock to the benefit of particular vegetation assemblages, nor how specific stocking rates might be used to suit best the spatial arrangement of different vegetation types within a moorland grazing unit. We don't adequately understand trajectories of vegetation change and recovery (including in the face of changing climate) and if and when key species will appear. Nor can we calculate optimal grazing levels to deliver multiple ecosystem services. Similarly, we don't know whether spatial patterns of grazing on moorland can be influenced to deliver spatially diverse grazing levels producing a range of outcomes on varied moorland.

7.17 We do not have a simple method of determining the optimum date for 'shutting up' upland hay meadows in any given year. It is likely that the growth and flowering of a number of meadow species will be affected to different extents by spring grazing, and that the effect is likely to be influenced by the change in season (Pinches *et al.* 2013). We need a simple method to help farmers decide how long they can leave livestock in their hay meadows before shutting the fields up for the summer.

7.18 We need better information from surveys of burning activities in order to formulate more effective management plans. There is a lack of consistency in the information recorded in surveys of moorland burning, which hampers the drawing of useful conclusions about floral and faunal recovery rates after different burning rotations (Glaves *et al.* 2013). In addition, previous and current research does not adequately account for intensity and/or severity of burns.

7.19 The impact of *Phytophthora* diseases on upland habitats. Tree diseases are receiving much attention, but two notifiable species of *Phytophthora* (*P. ramorum* and *P. kernoviae*) and a few non-notifiable species (*P. pseudosyringae, P. lateralis, P. citricola, P. austrocedrae*) are being found on moors and lowland heathlands, causing death to tree and shrub vegetation. As a result, some sites are seeing a decrease in otherwise common species in those habitats, such as bilberry (*Vaccinium myrtillus*). *P. austrocedrae* has recently been identified as the cause of dieback in juniper stands in Upper Teesdale.

8 Land management and water quality

What we know:

8.1 The Statutory Nature Conservation Bodies (SNCBs) have recently summarised their jointly agreed evidence requirements for freshwater conservation (Interagency Freshwater Group 2014). This is intended to guide the research priorities of the SNCBs in undertaking their biodiversity duties. It is also designed to influence others who have a role in freshwater and catchment management research so that conservation needs are fully considered. The published framework links high level themes to more detailed research areas and in turn links detailed research needs to policy needs under different drivers. The themes cover: a) environmental processes, impacts and management – research needs which will better define the nature of management responses needed; b) ecosystem integrity and resilience – research needs which better characterise the response of biological communities to human impacts; and c) biodiversity assessment and audit – the need for datasets and methods which provide a direct assessment of habitats and their integrity.

8.2 The research framework above deals only briefly with evidence needs relating to the land management tools for freshwater, and these are set out below.

8.3 Agriculture is a major source of nitrogen, phosphate, suspended sediment and Faecal Indicator Organism (FIO) pollution in freshwaters. High levels of nitrogen, especially in combination with other agricultural inputs, are one of the factors that have driven the observed decline in farmland biodiversity (Skinner *et al.* 1997). Factors contributing to increased nutrient loadings include the conversion of permanent pasture to arable cultivation, an increase in the area dedicated to cereal production and a substantial increase in average rates of inorganic fertiliser application (Foster 2000).

8.4 In recent years there have been considerable improvements in the efficiency with which agriculture uses resources, and these have led to reductions in levels of diffuse pollution. Farmers are using fertilisers and manures more efficiently and effectively, with average nitrogen application rates of nitrogen falling from 147kg/ha in 1987 to 95 kg/ha in 2008 and average phosphate use reduced by half to 20 kg/ha between 1983 and 2008 (Defra 2014a). This reduction in applications is feeding through to a reduction in diffuse pollution: in both Biodiversity 2020 (Defra 2014c) and Countryside Survey (Smart *et al.* 2010) reporting, most indicators associated with soils and freshwaters are now stable or improving.

8.5 Pollution from agriculture is cited as the likely cause in 33% of known failures (nutrients, Biochemical Oxygen Demand (BOD)/ammonia, sediment, morphology) to achieve Good Ecological Status for water bodies in England (Defra 2004). Diffuse pollution is impacting on the status of water bodies with the highest public use or conservation value, including Protected Areas such as vulnerable Natura 2000 habitats, as well as freshwater fish, drinking, bathing and shellfish waters (Defra 2004). Only 29% of river SSSIs are in favourable condition, although other pressures including hydrological and physical modification and non-native invasive species are also contributory factors (Natural England 2008). Initial results from boreholes near groundwater-fed wetland SSSIs across the UK suggest that nitrate levels present a long-term risk to the health of many/most groundwater-fed sites in the lowlands of England (UK Technical Advisory Group on the Water Framework Directive 2014).

Areas that are subject to active research and debate:

8.6 Developing land management options that can help address water quality issues. We know how to manage buffer strips for soil erosion and runoff mitigation, and where they should be sited (though translating that into practice can be difficult) (Natural England 2011). However, there is concern that current mechanisms may not always be adequate to achieve the degree of change in land management needed to improve the water quality sufficiently for some sites. For example more permanent changes in vegetation cover, such as extensively-managed grassland or woodland (e.g. Zhang & Hiscock 2011) may be required to reduce nutrient levels in ground-water in some areas. There is good evidence that Catchment Sensitive Farming (CSF) scheme uptake and the combination of advice and incentives, including dedicated infrastructure grants, has produced demonstrable water quality improvements in terms of pollutant loadings and contributions of achieving Water Framework Directive (WFD) and biodiversity objectives (Environment Agency & Natural England 2011, 2015). The CSF approach does however successfully engage farmers with pollution control. As a consequence of their understanding of the farm business and ability to establish rapport with farmers, CSF advisers became more trusted and had influence over land management decisions (AIC 2013).

8.7 Understanding the scale of action needed to achieve the water quality objectives required to implement the Water Framework Directive, both to achieve target condition for SSSIs and Natura 2000 sites and meet England Biodiversity Strategy targets, and to meet wider Protected Area and Good Ecological Status requirements. The optimal combination of measures (annual payments, capital payments, advice and regulation) needed to achieve these goals is not yet clear. In relation to SSSIs, we need to improve our ability to target management action through finer-scale modelling and field assessment of actions required to address diffuse water pollution impacts.

8.8 Evidence to support effective targeting of reductions in nitrogen emissions. We need this to improve our understanding of the relative significance of different sources of eutrophication in order to tackle the combined effects of atmospheric sources and aquatic sources of nitrogen affecting, for example, wetlands and other freshwater habitats. This will require fundamental research to improve our understanding of nutrient dynamics in such ecosystems.

9 Land management and atmospheric pollution

What we know:

9.1 Air pollution has caused widespread changes to species richness and distribution and to the quality of natural and semi-natural habitats in the UK (Stevens *et al.* 2011). 65% of the area of sensitive habitat in the UK (97% in England) exceeds critical loads for atmospheric nitrogen deposition (eutrophication) (JNCC 2014). This will reduce only slightly when existing national measures are put in place by 2020 (ROTAP 2012). The UK Habitats Directive report (JNCC 2013) showed that out of 77 Annex 1 habitats, 34 had air pollution attributed as a high pressure and a high threat.

9.2 Ammonia emissions from agriculture contribute significantly to atmospheric nitrogen deposition. At a national level, oxides of nitrogen (NO_x) and ammonia (NH_3) each contribute about 50% of the total nitrogen emission, but their contribution to nitrogen deposition at a local level varies between sites (Dragosits *et al.* in prep, 2015). Close to urban areas, large combustion sources or along motorway corridors, NO_x is the dominant contributor, whilst NH_3, predominantly from agricultural sources, dominates in more rural areas.

What we don't know:

9.3 The Statutory Nature Conservation Bodies (SNCBs) have recently issued for comment a framework for UK research and evidence needs on air pollution impacts on ecosystems. The SNCB framework considers evidence needs relating to ecosystem responses to changes in air pollution; assessing and reporting air pollution impacts and measures and remedies for air pollution. As the evidence base of air pollution impacts on biodiversity has increased, there is an increasing requirement to focus on identifying measures and delivery mechanisms to minimise the impacts and to optimise co-benefits in other policy areas (e.g. water quality, climate change, agriculture etc). Key gaps in evidence and capability that should be addressed to enable action to address air pollution impacts at site level include: a) understanding ecosystem response to future emission/deposition scenarios; b) uncertainties in the sensitivity of some nature conservation features and the effectiveness of mitigating measures; c) availability of information about local emission sources and local trends in deposition; d) improved tools to enable assessment in addressing atmospheric nitrogen impacts; and e) evidence to enable improved targeting of measures that will achieve multiple benefits.

10 Agri-environment scheme design, targeting and delivery

What we know:

10.1 The two-tier approach that Environmental Stewardship (ES) embodies has sparked a great deal of research interest (see for example Boatman *et al.* 2010). ES has been subject to an extensive programme of monitoring and evaluation since its introduction. The 2009 review of agri-environment schemes (Natural England 2009) demonstrates that ES has built on the achievements of the Classic schemes in many areas. Higher Level Stewardship (HLS) has been extensively used to bring SSSIs into appropriate management and in 2009 84% of eligible BAP priority habitat was under agreement. Entry Level Stewardship (ELS) has made a landscape-scale impact, with roughly 70% of Utilisable Agricultural Area (UAA) now subject to agreement and 41% of the hedges in England being actively managed for environmental purposes. A controlled trial conducted by the Centre for Ecology and Hydrology (CEH) on the Hillesden Estate (Heard *et al.* in press) has shown that when ELS-type management is applied systematically to an intensively farmed arable landscape it can produce a range of environmental benefits.

10.2 Agri-environment schemes need careful management if they are to consistently deliver good results. Agreement-scale baseline monitoring by CEH (Centre for Ecology and Hydrology 2010) has shown that the flexibility incorporated into HLS has not always been fully utilised to specify and ensure delivery of the complex, adaptive management required for the maintenance, restoration and re-creation of semi-natural habitats, though there is an increasing number of case studies demonstrating that HLS can successfully deliver such management (Natural England 2014). The advice and support for farmers provided by land management advisers can improve environmental outcomes (Defra (g))

10.3 Targeting is crucial to maximise scheme effectiveness. Where HLS options are more specifically targeted at the needs of particular biota they can be very effective in benefitting the targeted groups of species (Pywell *et al.* 2012; Natural England 2009). Butterfly monitoring studies have shown that targeted agri-environment schemes can increase local populations of species of butterflies with specialist habitat requirements (Fox *et al.* 2011).

10.4 Entry Level Stewardship (ELS) has not yet delivered the range of environmental benefits that was anticipated (Natural England 2009). The free choice of options, combined with the hands-off approach and some unforeseen limitations in the management prescribed have meant that the scheme has not yet been able to arrest the overall decline in the population of key farmland bird species, regarded as a key indicator of the state of farmland biodiversity. Recent research (Baker *et al.* 2012) has however shown that broad and shallow schemes like ELS do have the potential to benefit farmland birds at the population level if uptake of the key options targeting the factors limiting bird populations can be improved.

Areas under active research or debate:

10.5 The effectiveness and limitations of advice as a mechanism for influencing land management practice. The current strategy for addressing the under-performance of Entry Level Stewardship has been to enhance the advice available to agreement holders through the ELS Training and Information Programme (ETIP), and the effectiveness of this is being closely monitored. The Campaign for the Farmed Environment is also producing useful data which may help assess the effectiveness and the limitations of advice, both alone and in combination with payments. More work is needed to develop and test ways of engaging farmers more fully with environmental land management.

10.6 The extent to which farmers understand their agreements and have confidence in achieving the outcomes agreed with their Natural England Advisers. Current research under the joint Defra-NE programme (see Section 13) is exploring how well farmers with Environmental Stewardship agreements understand why they are doing things and how that affects their confidence that it will work.

10.7 The extent to which advice provision during the life of an agreement makes a difference to the outcomes delivered. It is usually assumed that one-to-one advice increases outcome focus and engagement with agreements (and stakeholder organisations frequently call for more support and advice in Environmental Stewardship). Current monitoring and evaluation studies (see Section 13) are assessing whether or not this is the case.

10.8 The extent to which agri-environmental management can deliver multiple benefits, and how best to achieve this. There is pressure to increase value for money by achieving multiple outcomes from a single intervention, but experience to date has been that interventions are most effective when clearly focused on a single, easily understood goal. It is not clear what combination of multi-objective management and carefully targeted single-purpose management will deliver the best value for money or whether this approach can be delivered without causing 'detrimental' change to other objectives.

10.9 The scale of future environmental land management requirements and how to bridge the gap between the scale of those environmental challenges and the available resources. Cao *et al.* (2009) identified the scale of future land management challenges, based on Government priorities of the time. These have evolved over the last 6 years and we no longer know the scale of the environmental challenge based on current Government priorities. This knowledge is essential if we wish to bridge the gaps between the scale of the environmental challenge and available resources. Reduced RDP spending will put greater emphasis on alternative mechanisms for rewarding environmental land management. Progress has been made in persuading water companies to invest in improved land management within their catchments. Little progress has been made in developing the voluntary offset market for carbon, or with mechanisms to reward land managers directly for the economic value of land-related outdoor recreation. This is particularly true in upland areas, which are well placed to provide a range of ecosystem services, but where only food production currently offers a return from the market.

10.10 The best approach to targeting agri-environmental management. The Hillesden Project has shown that an increase in the level of intervention above that of the current Entry Level Stewardship (ELS) can produce disproportionately higher environmental benefits (Heard *et al.* in press). More limited use of targeted options applied at a landscape scale is likely to be more successful and cost-effective (Mountford *et al.* 2013).

10.11 How to effectively integrate habitat and species conservation. Current habitat-focused management does not always provide for the full range of species that depend on these habitats (Webb *et al.* 2010). Tailoring habitat management to the precise needs of many different species is impossible in practice, but Webb *et al.* identified some general principles, most notably the importance of heterogeneity. It appears that agri-environment schemes may be producing habitats that are too uniform to support all the species that should be associated with them. The report lists many of the key features of individual habitats that are valuable for groups of species. More work is however needed on how best to convey this information to advisers and agreement holders, and how to get it built into scheme design

What we don't know:

10.12 The degree of culture shift achieved by agri-environment agreements. It is not known whether participation in an agri-environment agreement leaves a legacy of changed management practices if the contracts are not renewed. It is also unclear how to maintain positive and ongoing relationships with agreement holders once direct funding has ceased, in order to preserve environmental outcomes.

10.13 How to deliver landscape-scale working and functional ecological networks. Current policy assumes that this is 'a good thing' following the Lawton Review (Lawton *et al.* 2010), but changing management across a whole landscape is expensive, so this approach needs to be focused on the situations where it is necessary to achieve the desired end. We need to document the situations where landscape-scale working is necessary to achieve a desired goal and to understand the threshold levels of intervention that can deliver success. We also need to understand better how to deliver this in the most effective way (in terms of cost and outcome).

10.14 How to achieve sustainable intensification alongside an improved natural environment in the lowlands. The Foresight Report of the Future of Food and Farming (Foresight 2011) identified the need to achieve a further increase in food production, but to do this in ways that didn't cause another wave of environmental damage. However, the report did not identify how this could be done, though it suggested this would need a combination of existing best practice and the application of new technology.

10.15 How to make a reality of the ecosystem approach and to reconcile localism with delivery of Government's national priorities and international obligations. The Natural England Ecosystem Services Pilots have explored these issues (Waters *et al.* 2012). Other pilots, including the Environment Agency's (and others') catchment-based approach under the Water Framework Directive, are also exploring these issues (Wyborn and Bixler 2013).

10.16 How to maximise the flood mitigation potential of changes in land management. A recent major review (Parrott *et al.* 2009) found clear evidence of the benefits of using farmland to store floodwater, either on riparian washlands or estuarine managed re-alignment schemes. The review also found good evidence of local flood amelioration benefits from changes in land management, but concluded that quantifying the effectiveness of catchment-scale changes in land management practice in ameliorating downstream flooding is proving difficult. One technique that was identified as showing promise as a way of ameliorating extreme flood events at the large catchment scale is the establishment of additional flood plain woodland (Nisbet *et al.* 2011).

11 The wider benefits of land management changes delivered through agri-environment schemes

What we know:

11.1 Agri-environment schemes demonstrate positive cost-benefit ratios. A study of the wildlife, landscape and climate mitigation benefits of Environmental Stewardship (ES) (Defra 2010b), showed positive cost-benefit ratios based on a representative sample of the public's willingness to pay, with additional benefits from the value of the carbon saved by ES management. The cost-benefit of ES has been calculated as between 1.15 - 1.80. This is a conservative estimate as it excludes the valuation of water quality improvements, air quality improvements and carbon mitigation delivered by the scheme.

11.2 Agri-environment schemes have the potential to contribute to the provision of a range of ecosystem services. Their potential to do this was the subject of a recent review (Whittingham 2011).

11.3 Agri-environment schemes produce wider social and economic as well as environmental benefits. A study of the incidental socio-economic benefits of Environmental Stewardship (ES) (Defra 2010a) showed that Higher Level Stewardship in particular can have a significant positive impact on the rural economy, especially in more remote areas. For every £1 of ES scheme payment that goes to the agreement holder, 26 pence is generated off-farm in the local economy through direct expenditure and indirect and induced effects. Based on scheme spend in 2013, ES will generate £415m of spending in local economies and will sustain 778 jobs.

11.4 Sustainable food production depends on a 'healthy environment' and particularly on biodiversity. A Natural England-funded survey (Boatman *et al.* 2008) of the ecosystem services supporting agricultural production that have been provided by agri-environment schemes has shown the following:

- Soil, and the nutrients in it, is fundamental to agricultural production, while nutrient cycling, carbon sequestration, water regulation and water purification are also all reliant on soil. Water infiltration into soil slows the flow of water to rivers, which reduces the potential for flooding and soil erosion.
- Breeding improved plants and animals for agricultural purposes, such as increased yield or disease resistance, requires new genetic material. The two main sources of this are existing traditional varieties or breeds and the wild relatives of cultivated or domesticated forms. There are over 300 taxa that are wild relatives of UK crops and hence are a source of genetic diversity for use in plant breeding.
- Regulating pest species by natural enemies can be encouraged by providing appropriate habitats and resources and by reducing pesticide-induced mortality of those natural enemies. The research found that resources required by the predators of past can be provided by a number of options under Environmental Stewardship (ES), especially those for undersown spring cereals; enhanced stubbles; beetle banks; low input and species-rich grasslands and upland meadows.
- Pollination by insects is important for many crops to promote seed set and fulfil yield potential. Many ES options support pollinator species. In Britain and the rest of Europe, insect pollinators contribute to the production of over 80% of crop species. The research found that estimates of the economic value of pollination services to UK agriculture range from £186m to £567m per annum.

12 Current Natural England evidence projects

12.1 The main activity relating to evidence projects is undertaken as part of a collaborative programme with Defra's Sustainable Land and Soils Division. R&D projects and the Environmental Stewardship Monitoring and Evaluation programme delivered through this process are detailed in Section 13 below.

12.2 In addition there is one current Natural England-sponsored project that is exploring alternative chemical control methods for bracken and, in collaboration with English Heritage, the efficacy of non-chemical bracken control, particularly in protecting the historic environment.

13 Key external research programmes

13.1 **Defra Sustainable Land and Soils Evidence Programme.** This comprises a) a research and development programme and b) a monitoring and evaluation programme. Both are designed to support the ongoing development and delivery of environmental land management schemes in England.

- **Defra Sustainable Land and Soils research and development programme.** A long-term programme of research and development that includes many projects designed to inform agri-environment policy and option design, and provide the basis for guidance material for advisers. The programme is collaborative and Natural England manages a number of projects within the programme on behalf of Defra, though the funding comes from Defra's R&D budget. Details of the ongoing projects managed by Natural England are provided below:

Code	Project
BD1451	DIGFOR (Diversification of grassland through the manipulation of plant-soil interactions and the identification of indicators of restorability)
BD1459	Microsite (Techniques to enhance the establishment and persistence of poor-performing species in grassland restoration)
BD1460	Susgraz (An experiment to test sustainable management systems for unimproved neutral grassland)
BD5101	Milestones (Setting Indicators of Success for Species - rich grassland)
BD5001	Characterisation of soil structural degradation under grassland and development of measures to ameliorate its impact on biodiversity and other soil functions
BD5003	Managing Grassland Diversity For Multiple Ecosystem Services
BD2114	Effects of hedgerow management and restoration on biodiversity
BD5005	Provision of Ecosystem services in the ES scheme
BD5104	Restoration of blanket bog vegetation for biodiversity, carbon storage and water regulation
BD5105	Implications of grazing regimes on vegetation, invertebrates and livestock performance and following heather restoration on degraded heathland
BD5204	Improving the management and success of arable plant options in ELS and HLS
BD5209	Quantifying the effects of Entry Level Stewardship (ELS) and Higher Level Stewardship (HLS) on biodiversity and ecosystem services at the farm scale
BD5210	Effects of winter-long provision of seed rich habitats on seed eating farmland birds
LM0101	To develop an environmentally beneficial field-scale arable option for reducing blackgrass incidence
LM0202	A scoping study to develop a methodology that can be used to assess the value of agri-environment scheme options in the creation and maintenance of small-scale habitat mosaics to benefit priority species
LM0301	Reducing the impacts of predation on breeding waders using landscape-scale habitat management
LM0313	Woodland creation and ecological networks: Quantifying the relative importance of different attributes on biodiversity (Phase 1)
	Counterfactuals (Review of methodological approaches and analyses undertaken in the Defra/NE agri-environment monitoring and evaluation programme to improve assessment of scheme impacts)

- **Rural Development Programme ELM scheme monitoring and evaluation.** A programme of monitoring and evaluation to determine how well current agri-environment schemes are achieving environmental policy objectives, how well Natural England is delivering appropriate agreements, and whether individual agreements and management plans are achieving their indicators of success. The programme is delivered jointly by NE, FC, EA and Defra and includes a combination of in-house and externally contracted work. In addition there are also equivalent programmes of RDP monitoring and evaluation in Wales and in Scotland that provide relevant information. Details of the current externally contracted projects managed by Natural England are provided below:

Code	Project
LM0422	Monitoring the effects of English agri-environment schemes on upland breeding birds using the Upland Breeding Bird Survey (UBBS)
LM0423	Project to survey and assess Soil pH and nutrient status on sites of high botanical value
LM0425	Assessing the Effect of Policy Interventions on Agricultural Landscapes
LM0431	Long-term monitoring of the effects of agri-environment: moorland
LM0432	Assessing the impact of advice and support on the environmental outcomes of HLS agreements
LM0433	Assessing the role of advice and support in the establishment of HLS agreements
LM0434	Monitoring the impact of ES on Landscape Character and Quality
LM0435	Effectiveness of ES for the conservation of historic farm buildings
LM0436	Monitoring the response of farmland birds to Environmental Stewardship: ELS
LM0439	Assessing Resource Protection benefits of AE through water quality monitoring
LM0440	The value of grass margins as wildlife corridors
LM0441	Impacts of HLS on farmland birds: resurvey
LM0442	Long-term monitoring of the effects of agri-environment: lowland fen and bog
LM0443	Long-term monitoring of the effects of agri-environment: lowland grassland
LM0444	Soil characteristics of high value sites
LM0445	Whole Agreement Monitoring
LM0447	Monitoring of ELS Option EK21: Legume and herb-rich swards.
LM0448	Evaluating the impact of ES agreements on climate change adaptation
LM0449	Contribution of ES to conservation of Great Crested Newts
LM0450	Evaluating the relative importance of site and landscape characteristics on the effectiveness of restoring species-rich grassland communities through agri-environment schemes
LM0452	Impact of HLS on the conservation status of European protected reptiles on lowland heathland

13.2 Defra's Sustainable Intensification Platform (SIP). This programme is designed to consolidate research into how sustainable intensification can be applied at the feature scale, at a landscape scale, and within the supply chain industries. It comprises three interlinked research projects that will investigate ways to increase farm productivity while reducing environmental impacts and enhancing ecosystem services, and aims to develop more integrated and collaborative ways of funding, conducting and applying agricultural research. Defra is investing £4.5m in the SIP over the period 2014-2017. The initial three research projects are:

- Project 1. Integrated farm management for improved economic, environmental and social performance.
- Project 2. Opportunities and risks for farming and the environment at landscape scales.
- Project 3. Scoping study on the influence of external drivers and actors on the sustainability and productivity of English and Welsh farming (6-month scoping study).

13.3 NERC Biodiversity and Ecosystem Services (BESS) programme. This is a six-year programme with three main themes: a) Functional relationships between biodiversity and ecosystem services, b) resilience of biodiversity-ecosystem service relationships to changing conditions and c) indicators for the monitoring and evaluation of ecosystem services. It is supporting four multi-institutional research consortia in four different landscapes: lowland agriculture, upland rivers, urban and coastal systems. The Wessex BESS consortium is looking at biodiversity and the provision of multiple ecosystem services in current and future lowland multifunctional landscapes is particularly relevant to land management.

14 Key references

ADAS. 2014. *Securing and Maximising the Environmental Gain from Arable Reversion*. Defra Research Report LM0427. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=18838&FromSearch=Y&Publisher=1&SearchText=LM0427&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

AGRICULTURAL INDUSTRIES CONFEDERATION (AIC). 2013. *The Value of Advice Project Report*. URL: **www.agindustries.org.uk/latest-documents/value-of-advice-project-report/**

ALONSO, I., HOLLOWAY, J., EDE, J., ROCHFORD, J., STEPHEN, M. & GLAVES, D. 2009. Guidance on protecting soils and the historic environment when restoring or re-creating lowland heathland. Natural England Technical Information Note TIN054. URL: **http://publications.naturalengland.org.uk/publication/33016**

ALONSO, I., WESTON, K., GREGG, R. & MORECROFT, M. 2012. *Carbon storage by habitat - Review of the evidence of the impacts of management decisions and condition on carbon stores and sources.* Natural England Research Report NERR043. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/1412347**

ANDERSON, P. & YALDEN, D. W. 1981. Increased sheep numbers and the loss of heather moorland in the Peak District, England. Biological Conservation, 20, 195-213.

ANGUS, A., BURGESS, P., MORRIS, J. & LINGARD, J. 2009. Agriculture and land use: Demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. *Land Use Policy,* 26 Supplement 1, S230–S242.

ANON. 2008. *Permaculture Miracles in the Austrian Mountains.* URL: **www.celsias.com/article/permaculture-miracles-in-the-austrian-mountains/**

BADLEY, J, & ALLCOM, R.I. 2006. Changes in bird use following managed realignment at RSPB Frieston Shore RSPB reserve. Conservation Evidence 2006 **3** 102-105

BAIN, C.G., BONN, A., STONEMAN, R., CHAPMAN, S., COUPAR, A., EVANS, M.,GEAREY, B., HOWAT, M., JOOSTEN, H., KEENLEYSIDE, C., LABADZ, J., LINDSAY, R.,LITTLEWOOD, N., LUNT, P., MILLER, C.J., MOXEY, A., ORR, H., REED, M., SMITH, P., SWALES, V., THOMPSON, D.B.A., THOMPSON, P.S., VAN DE NOORT, R., WILSON, J.D. & WORRALL, F. 2011. *IUCN UK Commission of Inquiry on Peatlands*. Edinburgh: IUCN UK Peatland Programme.

BAKER, D., FREEMAN, S., GRICE, P. & SIRIWARDENA, G. 2012. Landscape-scale responses of birds to agri-environment management: a test of the English Environmental Stewardship Scheme. *Journal of Applied Ecology,* 49, 871-882.

BARNES, A. P., TOMA, L., WILLOCK, J., & HALL, C. 2013. *Comparing a 'budge' to a 'nudge': Farmer responses to voluntary and compulsory compliance in a water quality management regime*. Journal of Rural Studies 32.

BOATMAN, N., BRADBURY, R., CRITCHLEY, N., HOLLAND, J., MARSHALL, J. & OGILVY, S. Eds. 2007. *Delivering Arable Biodiversity*. Aspects of Applied Biology 81.

BOATMAN, N., GREEN, M., HOLLAND, J., MARSHALL, J., RENWICK, A., SIRIWARDENA, G., SMITH, B. & DE SNOO G. Eds. 2010. *Agri-environment schemes – what have they achieved and where do we go from here?* Aspects of Applied Biology 100.

BOATMAN, N., RAMWELL, C., PARRY, H., JONES, N., BISHOP, J., GASKELL, P., SHORT, C., MILLS, J. & DWYER, J. 2008. *A review of environmental benefits supplied by agri-environment schemes.* Report FST20/79/041 for the Land Use Policy Group.

BOLTON, M., TYLER, G., SMITH, K. & BAMFORD, R. 2007. The impact of predator control on lapwing *Vanellus vanellus* breeding success on wet grassland nature reserves. *Journal of Applied Ecology,* 44, 434-544.

BRITT, C., TUFFNELL, N., KIRKHAM, F., ROBERTS, A. & SPARKS, T. 2011. *Hedgerow Management: A survey of land managers' and contractors' practices and attitudes.* Final report of Defra research project BD2117. London: Department for the Environment, Food and Rural Affairs.

BROWN, A., GILBERT, G. & WOTTON, S. 2012. Bitterns and Bittern Conservation in the UK. *British Birds,* 105, 58–87.

BROWN, L.E., HOLDEN, J. & PALMER, S.M. 2014. *Effects of moorland burning on the ecohydrology of river basins. Key findings from the EMBER project*. University of Leeds.

BTO. 2007. Understanding the demographic mechanisms underlying effective deployment of winter prescriptions for farmland bird recovery. Defra R&D report BD1628. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=13023&FromSearch=Y&Publisher=1&SearchText=BD1628&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

BUCKINGHAM, D.L., BENTLEY, S., DODD, S. & PEACH, W.J. 2011. Seeded ryegrass swards allow granivorous birds to winter in agriculturally improved grassland landscapes. *Agriculture, Ecosystems & Environment,* 142, 256-265.

CAO, Y., ELLIOTT, J., MCCRACKEN, D., ROWE, K., WHITEHEAD, J. & WILSON L. 2009. *Estimating the Scale of Future Environmental Land Management Requirements for the UK*. *Report to the Land Use Policy Group*. ADAS UK Ltd and Scottish Agricultural College.

CARROLL, J., ANDERSON, P., CAPORN, S., EADES, P., O'REILLY, C. & BONN, A. *Sphagnum in the Peak District - Current Status and Potential for Restoration.* Final Report – March 2009. Moors for the Future Report No 16. Moors for the Future Partnership.

CATCHPOLE,T. & PRIEST, R. 2012. *Turning the Plough, Update Assessment 2012. Summary Report for English Heritage.* Gloucester County Council.

CENTRE FOR ECOLOGY AND HYDROLOGY. 2010. *First interim report from the agreement-scale monitoring of HLS agreements.* URL: **http://neintranettechnical/content/technical/docs/docs_10/CEH_MoA_First_Year_Report_finalised_text_(231110).pdf**

CLARKE, J.H., COOK, S.K., HARRIS, D., WILTSHIRE, J.J.J., HENDERSON, I.G., JONES, N.E., BOATMAN, N.D., POTTS, S.G., WESTBURY, D.B., WOODCOCK, B.A., RAMSAY, A.J., PYWELL, R.F., GOLDSWORTHY, P.E., HOLLAND, J.M., SMITH, B.M., TIPPLES, J., MORRIS, A.J., CHAPMAN, P. & EDWARDS, P. 2007. The SAFFIE Project Report. ADAS, Boxworth, UK. URL: **http://archive.hgca.com/document.aspx?fn=load&media_id=3567&publicationId=3919**

CRITCHLEY, C. N. R., ADAMSON, H. F., MCLEAN, B. M. L. & DAVIES, O. D. 2008. Vegetation dynamics and livestock performance in system-scale studies of sheep and cattle grazing on degraded upland wet heath. *Agriculture Ecosystems & Environment*, 128, 59-67.

DEFRA (a) (in prep) *Diversification of grassland through the manipulation of plant-soil interactions and the identification of indicators of restorability*. Defra Research Project BD1451

DEFRA (b) (in prep) *Improving the effectiveness of grassland restoration and creation options: development of a methodology for setting indicators of success and assessing progress.* Defra Research Project BD5101

DEFRA (c) (in prep) *Techniques to enhance the establishment and persistence of poor-performing species in grassland restoration*. Defra Research Project BD 1459

DEFRA (d) (in prep) *Monitoring the impact of ES on Landscape Character and Quality.* DEFRA Research Project LM0434

DEFRA (e) (in prep) *Restoration of blanket bog vegetation for biodiversity, carbon storage and water regulation.* Defra Research Project BD5104

DEFRA (f) (in prep) *Investigation of peatland restoration (grip blocking) techniques to achieve best outcomes for methane and greenhouse gas emissions / balance.* Defra Research Project SP1202

DEFRA (g) (in prep) Assessing the impact of advice and support on the environmental outcomes of HLS agreements. Defra Research Project LM0432

DEFRA (h) (in prep) Sustainable management systems for unimproved neutral grassland BD1460. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=14700&FromSearch=Y&Publisher=1&SearchText=BD1460&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

DEFRA. 2004a. *Rural Strategy*. 2004. PB 9728. URL:
http://archive.defra.gov.uk/rural/documents/policy/strategy/rural_strategy_2004.pdf

DEFRA. 2004b. *Strategic Review of Diffuse Water Pollution from Agriculture. Initial Appraisal of Policy Instruments to Control Water Pollution from Agriculture.* URL:
http://archive.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/intro.htm#2

DEFRA. 2006. *Ecologically sustainable grazing management of lowland unimproved neutral grassland and its effect on livestock performance.* BD1440. URL:
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=9252&FromSearch=Y&Publisher=1&SearchText=BD14&GridPage=2&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

DEFRA. 2010a. *The incidental socio-economic benefits of Environmental Stewardship.*

DEFRA. 2010b. *Estimating the wildlife and landscape benefits of Environmental Stewardship.*

DEFRA. 2010c. *Maps of livestock populations in 2000 and 2010 across England.* URL:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/183109/defra-stats-foodfarm-landuselivestock-june-detailedresults-livestockmaps111125.pdf

DEFRA. 2011a. Crop areas, yields and production, and livestock populations: 2011 UK – provisional results. URL:
http://webarchive.nationalarchives.gov.uk/20130123162956/http:/www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-june-statsnotice-uk-111006.pdf

DEFRA. 2011b. Biodiversity 2020: A strategy for England's wildlife and ecosystem services. London: Defra.

DEFRA. 2011c. *Observatory monitoring framework – indicator data sheet - Indicator B11: Crop and Milk Yields.* URL:
www.gov.uk/government/uploads/system/uploads/attachment_data/file/326713/agindicator-b11-03jul14.pdf

DEFRA. 2011d. **Social Research Evidence Review to Inform Natural Environment Policy. DEFRA NE0109.**

DEFRA. 2012. *Sustainable nutrient management of semi-natural neutral grasslands.* Research contract BD1468. URL:
http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16130

DEFRA 2013a. *Indicator DE5: Farmland bird populations. Observatory Monitoring Framework – indicator data sheet.* URL:
www.gov.uk/government/uploads/system/uploads/attachment_data/file/267556/agindicator-de5-18dec13.pdf

DEFRA. 2013b. *Establishing an improved baseline for monitoring and evaluating historic environment interventions in Environmental Stewardship (SHINE2013)*. DEFRA LM0426. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=18837&FromSearch=Y&Publisher=1&SearchText=LM0426&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

DEFRA. 2013c. *Developing a method for reporting and monitoring the direct and cumulative impacts of Environmental Stewardship on the maintenance and enhancement of landscape character and quality*. Research contract BD5303. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17454&FromSearch=Y&Publisher=1&SearchText=BD5303&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

DEFRA. 2014a. *The British Survey of Fertiliser Practice: Fertiliser use on farm for the 2013 crop year.* URL: **www.gov.uk/government/uploads/system/uploads/attachment_data/file/301475/fertiliseruse-statsnotice-08apr14.pdf**

DEFRA. 2014b. *Effects of woodland structure on woodland bird populations – an assessment of the effects of changes in woodland structure on bird populations as a result of woodland management practices and deer browsing* – Defra research report WC0793. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17511&FromSearch=Y&Publisher=1&SearchText=WC0793&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

DEFRA. 2014c. *Biodiversity 2020: a strategy for England's wildlife and ecosystem services Indicators*. URL: **www.gov.uk/government/uploads/system/uploads/attachment_data/file/383902/England_full_2014_finalv2.pdf**

DENNIS, P., YOUNG, M. R., HOWARD, C. L. & GORDON, A.J. 1997. The response of epigeal beetles to varied grazing regimes on upland *Nardus stricta* grasslands. *Journal of Applied Ecology*, 34, 433-443.

DENNIS, P., YOUNG, M. R. & BENTLEY, C. 2001. The effects of varied grazing management on epigeal spiders, harvestmen and pseudoscorpions of *Nardus stricta* grassland in upland. *Scotland.Agriculture, Ecosystems and Environment*, 86, 39-57.

DENNIS, P., ASPINALL, R. J. & GORDON, I. J. 2002. Spatial distribution of upland beetles in relation to landform, vegetation and grazing management. *Basic and Applied Ecology*, 3, 183-193.

DENNIS, P., SKARTVEIT, J., MCCRACKEN, D. I., PAKEMAN, R. J., BEATON, K., KUNAVER, A. & EVANS, D. M. 2008. The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology*, 45, 279-287.

DICKS, L. V., SHOWLER, D. A. & SUTHERLAND, W. J. 2010. *Bee conservation, evidence for the effects of interventions.* Synopses of Conservation Evidence, Volume 1. Exeter: Pelagic Publishing.

DRAGOSITS. 2014. *Identification of potential Remedies for Air (nitrogen) Pollution Impacts on Designated Sites (RAPIDS),* in preparation. Defra Research Contract AQ0834. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=18921&FromSearch=Y&Publisher=1&SearchText=Identification of potential Remedies for Air &SortString=ProjectCode&SortOrder=Asc&Paging=10#Description**

ECOSCOPE. 2003. *Review of agri-environment schemes – monitoring information and R&D results.* Report to Defra (Project RMP/1596). Ecoscope Applied Ecologists, St Ives, Cambridgeshire.

ELP & ASH, N. 2010. *New Opportunities For The Sustainable Management Of Fens: Reed Pelleting, Composting And The Productive Use Of Fen Harvests*. Final Report, Ecology, Land and People (ELP). Norwich: Broads Authority.

ENGLISH HERITAGE. 2009. *Heritage at Risk register.* London: English Heritage.

ENVIRONMENT AGENCY & NATURAL ENGLAND. 2011. *Catchment Sensitive Farming Phase 1 & 2 Evaluation (JP005).* **Catchment Sensitive Farming Phase 1 & 2 Evaluation - JP005.**

ENVIRONMENT AGENCY & NATURAL ENGLAND. 2015. *Catchment Sensitive Farming Evaluation Report - Phases 1 to 3 (2006 - 2014)(in press).*

FORD, H., GARBUTT, A., JONES, L. & JONES, D. L. 2013. *Grazing management in saltmarsh ecosystems drives invertebrate diversity, abundance and functional group structure.* Insect Conservation and Diversity, 6: 189–200. doi: 10.1111/j.1752-4598.2012.00202.x

FORESIGHT. 2011. *The Future of Food & Farming Final Project Report.* London: The Government Office for Science.

FOREST RESEARCH. 2009. *Trends, long term survival and ecological values of hedgerow trees: development of populations models to inform strategy.* URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14823**

FOSTER, S.S.D. 2000. Assessing and controlling the impacts of agriculture on groundwater – from barley barons to beef bans. *Quarterly Journal of Engineering Geology and Hydrology*, 33, 263-280.

FOX, R., BRERETON, T.M., ASHER, J., BOTHAM, M.S., MIDDLEBROOK, I. ROY, D.B. & WARREN, M.S. 2011. *The State of the UK's Butterflies 2011*. Wareham: Butterfly Conservation and the Centre for Ecology & Hydrology.

FRASER, M.D., THEOBALD, V.J., GRIFFITHS, J.B, MORRIS, S.M. & MOORBY, J.M. 2009. Comparative diet selection by cattle and sheep grazing two contrasting heathland communities. *Journal of Agriculture, Ecosystems and Environment,* 129. 182-192.

FULLER, R. M. 1987. The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-1984. *Biological Conservation*, 40, 281-300.

GAME AND WILDLIFE CONSERVATION TRUST. 2010. *Conserving the brown hare.* Fordingbridge: Game and Wildlife Conservation Trust.

GARDNER, S. M., HETHERINGTON, S. L. & ALLEN, D. 2002. *Assessment of vegetation change and Calluna/Nardus interactions in relation to spatial variation in grazing pressure on upland moor.* Final Report to Defra/WOAD Contract BD1211.

GASKELL, P, EDWARDS. R & BIBBY.P. 2009. *Historic Farm Buildings: Extending the Evidence Base*. London: English Heritage. URL: **www.english-heritage.org.uk/publications/historic-farm-buildings-extending-the-evidence-base/historic-farm-buildings-ext-evidence-base.pdf**

GLAVES, D., MORECROFT, M., FITZGIBBON, C., LEPITT, P., OWEN, M. & PHILLIPS, S. 2013. *Natural England Review of Upland Evidence 2012 – The effects of managed burning on upland peatland biodiversity, carbon and water.* Natural England Evidence Review, NEER004. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/5978072**

GORDON, C., EMMETT, B. A., JONES, M. L. M., BARDEN, T., WILDIG, J., WILLIAMS, D. L., WOODS, C., BELL, S. A., PUGH, B., NORRIS, D.A., ASHENDEN, T. W., RUSHTON, S. P. & SANDERSON, R. A. 2001. *Grazing and Nitrogen interactions in upland acid moorland.* CCW Research Report 01/22 and preceding reports.

GOWING, D. J. G. 2004. Lowland wet grassland community guidelines. *In* Brooks, A, W., José, P, V. and Whiteman, M, I. Eds *Ecohydrological guidelines for lowland wetland Plant Communities.* Environment Agency, Peterborough. Pp16-36.

GRACE, M., DYKES, A., THORP, S. & CROWLE, A. 2013. *The impacts of tracks on the integrity and hydrological function of blanket peat.* Natural England Evidence Review NEER002. Sheffield, Natural England. URL: **http://publications.naturalengland.org.uk/publication/5724597**

GRANT, S. A., SUCKLING, D. E., SMITH, H. K., TORVELL, L., FORBES, T. D. A. & HODGSON, J. 1985. Comparative studies of diet selection by sheep and cattle: the hill grasslands. *Journal of Ecology*, 73, 987-1004.

GRANT, S. A., TORVELL, L., SMITH, H. K., SUCKLING, D. E., FORBES, T. D. A. & HODGSON, J. 1987. Comparative studies of diet selection by sheep and cattle: blanket bog and heather moor. *Journal of Ecology,* 75, 947-960.

HALL, D. 2001. *Turning the Plough, Midland open fields: landscape character and proposals for management.* English Heritage & Northamptonshire County Council.

HARMER, R., KERR, G. & THOMSPSON, R. 2010. *Managing native broadleaved woodland.* Edinburgh, TSO.

HARTLEY, S. E. 1997. The effects of grazing and nutrient inputs on grass-heather competition. *Botanical Journal of Scotland*, 49 (2), 315-324.

HARTLEY, S. E. & MITCHELL, R. J. 2005. Manipulation of nutrients and grazing levels on heather moorland: changes in *Calluna* dominance and consequences for community composition. *Journal of Ecology*, 93, 990-1004.

HAWLEY, G., ANDERSON, P., GASH, M., SMITH, P., HIGHAM, N., ALONSO, I., EDE, J. & HOLLOWAY, J. 2008. *Impact of heathland restoration and re-creation techniques on soil characteristics and the historical environment.* Natural England Research Report, Number 010. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/37001**

HEARD, M.S., BOTHAM,M., BROUGHTON, R., CARVELL, C., HINSLEY, S., WOODCOCK, B. & PYWELL, R.F. in press. *Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment.* NERC Centre for Ecology and Hydrology.

HEWINS ECOLOGY. 2011. *Survey of Higher Level Stewardship option HK8: creation of species-rich semi-natural grassland*. Report to Natural England (contract no. 23558).

HEWINS, E., TOOGOOD, S., ALONSO, I., GLAVES, D.J., COOKE, A. & ALEXANDER, R. 2007. *The condition of lowland heathland: results from a sample survey of non-SSSI stands in England.* Natural England Research Report 002. URL: **http://publications.naturalengland.org.uk/publication/36001**

HEWINS, E.J, PINCHES, C., ARNOLD, J., LUSH, M., ROBERTSON, H. & ESCOTT, S. 2005. *The condition of lowland BAP Priority grasslands: results from a sample survey of non- statutory stands in England*. English Nature Research Report No 636. Peterborough. URL: **http://publications.naturalengland.org.uk/publication/106007**

HINSLEY, S. A., REDHEAD, J. W., BELLAMY, P. E., BROUGHTON, R. K., HILL, R. A., HEARD, M. S. & PYWELL, R. F. 2010. Testing agri-environment delivery for farmland birds at the farm scale: the Hillesden experiment. *Ibis,* 152, 500–514.

HOBBS, N.B. 1986. Mire morphology and the properties and behaviour of some British and foreign peats. *Quarterly Journal of Engineering Geology*, 19, 7-80.

HODGSON, J., FORBES, T.D.A., ARMSTRONG, R.H., BEATTIE, M.M. & HUNTER, E.A. 1991. Comparative studies of the ingestive behaviour and herbage intake of sheep and cattle grazing indigenous hill plant communities. *Journal of Applied Ecology*, 28, 205-227.

HODGSON, J.A., KUNIN, W.E., THOMAS, C.D., BENTON, T.G. and GABRIEL, D. 2010. Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. *Ecology Letters*, 13, 1358-1367.

HOLDEN, J. 2005. Peatland hydrology and carbon release: why small-scale process matters. *Phil. Trans. R. Soc. A*, 363, 2891-2913.

HOLDEN, J. 2006. Sediment and particulate carbon removal by pipe erosion increase over time in blanket peatlands as a consequence of land drainage. *Journal of Geophysical Research,* 111, 6pp. URL: **http://onlinelibrary.wiley.com/doi/10.1029/2005JF000386/pdf**

HOLDEN, J. 2009. *A grip-blocking overview.* Moors for the Future website. URL: **www.moorsforthefuture.org.uk/sites/default/files/Holden%20(2009)%20grip%20block%20review.pdf**

HOLDEN, J., CHAPMAN, P.J. & LABADZ, J.C. 2004. Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration. *Progress in Physical Geography*, 21(1), 95-123.

HOLDEN, J., GASCOIGNE, M. & Bosanko, N.R. 2007. Erosion and natural revegetation associated with surface land drains in upland peatlands. *Earth Surface Processes and Landforms*, 32(10), 1547-1557.

HOLDEN. J., EVANS, M.G., BURT, T.P. & HORTON, M. 2006. Impact of land drainage on peatland hydrology. *Journal of Environmental Quality*, 35, 1764-1778.

INTERAGENCY FRESHWATER GROUP 2014 . A UK Research Framework for Freshwater Conservation. Version 2. 3 December 2014. URL: **http://jncc.defra.gov.uk/page-5415**

HULME, P. D., MERRELL, B. G., TORVELL, L., FISHER, J. M., SMALL, J. L. & PAKEMAN, R. J. 2002. Rehabilitation of degraded *Calluna vulgaris* (L) Hull- dominated wet heath by controlled sheep grazing. *Biological Conservation* 107, 351-363.

JEFFERSON, R.G. 2005. The conservation management of upland hay meadows in Britain: a review. *Grass & Forage Science*, 60, 322-331.

JOINT NATURE CONSERVATION COMMITTEE (JNCC). 2013. *The UK Habitats Directive* report 2013. URL: **http://jncc.defra.gov.uk/article17**

JOINT NATURE CONSERVATION COMMITTEE (JNCC). 2014. In Biodiversity Indicators 2014. B5a Air Pollution. URL: **http://jncc.defra.gov.uk/page-4245**

JONES, A.G. & POWER, S.A. 2012. Field-scale evaluation of effects of nitrogen deposition on the functioning of heathland ecosystems. *Journal of Ecology*, 100, 331-342.

KIRBY, K.J. 2007. The contribution of coppice management to wildlife conservation. *In:* A SHEPLEY, ed. *21st Century Coppice.* pp9-14.Penrith: Coppice Association North West.

KIRKHAM, F.W., DAVIS, M., FOWBERT, J.A., HOOKE, D., PARKIN, A.B. & SHERWOOD, A.J. 2006. *Evaluation of Arable Reversion Agreements in the Countryside Stewardship and Environmentally Sensitive Areas Schemes.* DEFRA Research Project MA01015

KIRKHAM, F.W., DUNN, R.M., TALLOWIN, J.R.B., BHOGAL, A., CHAMBERS, B.J. & BARDGETT, R.D. 2014. Ecologically sustainable fertility management for the maintenance of species-rich hay meadows: a 12-year fertilizer and lime experiment. *Journal of Applied Ecology*, 51, 152-161.

LAKE, S., BULLOCK, J. M. & HARTLEY, S. 2001. *Impacts of livestock grazing on lowland heathland.* English Nature Research Report no. 422. Peterborough: English Nature. URL: **http://publications.naturalengland.org.uk/publication/50034**

LAWTON, J.H., BROTHERTON, P.N.M., BROWN, V.K., ELPHICK, C., FITTER, A.H., FORSHAW, J., HADDOW, R.W., HILBORNE, S., LEAFE, R.N., MACE, G.M., SOUTHGATE, M.P., SUTHERLAND, W.J., TEW, T.E., VARLEY, J. & WYNNE, G.R. 2010. *Making Space for Nature: a review of England's wildlife sites and ecological network.* Report to Defra.

LINDSAY, R. 2010. *Peatbogs and carbon: a critical synthesis to inform policy development in oceanic peat bog conservation and restoration in the context of climate change.* A report for RSPB Scotland from the Environmental Research group, University of East London. URL: **www.rspb.org.uk/Images/Peatbogs_and_carbon_tcm9-255200.pdf**

LITTLE, J. 2011. Assessment of the use of gorse and heather arisings as a feedstock for commercial pellet production. Feasibility report to the FC – Part 2. URL: **www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/BEC_TECHNICAL/RESEARCH%20AND%20STUDIES/VIRGIN%20WOOD%20AND%20FORESTRY%20STUDIES/FORESTRY%20COMMISSION%20GORSE%20AND%20HEATHER%20FOLLOW%20UP%20PELLET%20TRIALS.PDF**

LITTLEWOOD, N. A. 2008. Grazing impacts on moth diversity and abundance on a Scottish upland estate. *Insect Conservation and Diversity*, 1, 151-160.

MACDONALD, M.A., COBBOLD, G., MATHEWS, F., DENNY, M.J.H., WALKER, L.K., GRICE, P.V. & ANDERSON, G.Q.A. 2012. Effects of agri-environment management for cirl buntings on other biodiversity. *Biodiversity Conservation* June 2012, Volume 21, pp 1477-1492.

MACDONALD DW, JOHNSON PJ (2000) Farmers and the custody of the countryside: trends in loss and conservation of non-productive habitats 1981-1998. *Biological Conservation* 94: 221-234.

MAGIC. 2014. URL: **www.magic.gov.uk/**

MALCOLM, A., BOLTON, M., BUTCHER, N., HOCCOM, D.G., SMART, J. & WILLIAMS, G. 2009. Predation of breeding waders on lowland wet grassland – is it a problem? *British Wildlife,* 2009, 29-38.

MALTBY, E., ORMEROD, S., ACREMAN, M., BLACKWELL, M., DURANCE, I., EVERARD, M., MORRIS, J., SPRAY, C. 2011. in *The UK National Ecosystem Assessment Technical Report.* UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.

MALPAS, L.R., SMART, J., DREWITT, A.L., SHARPS, E. & GARBUTT, A. (in prep.) Continued declines of Redshank *Tringa totanus* breeding on saltmarsh in Great Britain: is there a solution to this conservation problem? *Bird Study.*

MALPAS, L., SMART, J. & GARBUTT, A. 2011. *The abundance of redshank Tringa totanus breeding on saltmarshes in Great Britain: results of a 2011 survey.* Unpublished RSPB Report to Natural England, RSPB, Sandy.

MARTIN, D., FRASER, M., PAKEMAN, R. & MOFFAT, A. 2013. *Natural England Review of Upland Evidence 2012 – Impact of moorland grazing and stocking rates.* Natural England Evidence Review, Number 006. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/5976513**

MASKELL, L.C., SMART, S.M., BULLOCK, J.M., THOMPSON, K., STEVENS, C.J. 2010. Nitrogen deposition causes widespread loss of species richness in British habitats. *Global Change Biol.* 16, 671-679.

McBRIDE, A., DIACK, I., DROY, N., HAMILL, B., JONES, P., SCHUTTEN, J., SKINNER, A. & STREET, M. 2011. *The Fen Management Handbook*. Perth: Scottish Natural Heritage.

MILNE, J., PAKEMAN, R. J., KIRKHAM, F. W., JONES, I. P. & HOSSELL, J. 2002. Biomass production of upland vegetation types in England and Wales. *Grass and Forage Science*, 57, 373-388.

MOUNTFORD, J.O. & COOKE, A.I. (eds), AMY, S.R., BAKER, A., CAREY, P.D., DEAN, H.J., KIRBY, V.G., NISBET, A., PEYTON, J.M., PYWELL, R.F., REDHEAD, J.W. & SMART, S.M. 2013. *Monitoring the outcomes of Higher Level Stewardship: Results of a 3-year agreement monitoring programme.* Natural England Commissioned Reports, Number 114. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/11462046**

NATURAL ENGLAND. 2008. *State of the Natural Environment 2008.* Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/31043**

NATURAL ENGLAND. 2009. *Agri-environment schemes in England 2009, a review of results and effectiveness.* URL: **http://publications.naturalengland.org.uk/publication/46002**

NATURAL ENGLAND. 2011. *Protecting water from agricultural run-off: buffer strips.* Technical Information Note 100. Protecting water from agricultural run-off: buffer strips - TIN100. URL: **http://publications.naturalengland.org.uk/publication/31003**

NATURAL ENGLAND. 2013. *Natural England Evidence Reviews.* URL: **http://publications.naturalengland.org.uk/category/5968803**

NATURAL ENGLAND. 2014. *Agri-environment case studies: Higher Level Stewardship* URL: **http://publications.naturalengland.org.uk/category/3565785**

NEWTON, A., STEWART, G.B., MYERS, G., LAKE, S., BULLOCK, J. & PULLIN, A.S. 2009. *How does the impact of grazing on heathland compare with other management methods?* Systematic review 14. Collaboration for Environmental Evidence. Birmingham: Centre for Evidence-Based Conservation.

NISBET, T., SILGRAM, M., SHAH, N., MORROW, K. & BROADMEADOW, S. 2011. *Woodland for Water: Woodland measures for meeting Water Framework Directive objectives.* Forest Research Monograph, 4. Surrey: Forest Research.

NISBET, T.R., ORR, H. & BROADMEADOW, S.B. 2008. *Using woodland for soil protection and sediment control.* In: Proceedings of the SAC and SEPA Biennial Conference on Land Management in a Changing Environment, Edinburgh, 26-27 March 2008, pp 84-90.

NORRIS, K., COOK, T., O'DOWD, B. & DURDIN, C. 1997. The density of redshank *Tringa totanu*s breeding on the salt-marshes of the Wash in relation to habitat and its grazing management. *Journal of Applied Ecology*, 34, 999-1013.

OOM, S. P., SIBBALD, A. M., HESTER, A. J., MILLER, D. R. & LEGG, C. J. 2008. Impacts of sheep grazing a complex vegetation mosaic: Relating behaviour to vegetation change. *Agriculture, Ecosystems and Environment*, 124, 219-228.

OOM, S. P., HESTER, A. J. & LEGG, C. J. 2010. Grazing across grass:shrub boundaries: Can spatial heterogeneity increase resistance? *Agriculture Ecosystems & Environment*, 139, 159-166.

OXFORD ARCHAEOLOGY. 2006. *Conservation of Scheduled Monuments in Cultivation* (COSMIC) BD1704: Final report to Defra.

OXFORD ARCHAEOLOGY & CRANFIELD UNIVERSITY. 2009. *Trials to identify soil cultivation practices to minimise the impact on archaeological sites* (Defra project number BD1705) & Effects of arable cultivation on archaeology (EH Project number 3874) known collectively as TRIALS - Final report to Defra. URL: **http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=12496**

PAKEMAN, R.J., HULME, P.D., TORVELL, L. & FISHER, J.M. 2003. Rehabilitation of degraded dry heather *Calluna vulgaris* moorland by controlled sheep grazing. *Biological Conservation*, 114, 389-400.

PALMER, S. C. F., HESTER, A. J., ELSTON, D. A., GORDON, I. J. & HARTLEY, S. E. 2003. The perils of having tasty neighbours: Grazing impacts of large herbivores at vegetation boundaries. *Ecology*, 84, 2877-2890.

PARROTT, A., BROOKS, W., HARMAR, O. & PYGOTT, K. 2009. Role of rural land use management in flood and coastal risk management. *Flood Risk Management*, 2, 272-284.

PEACH, W., BUCKINGHAM, D., WATTS, P., DAVIES, M., CHAPPLE, D., WHEELER, K., MASTERS, G., MACZEY, N., BROOK, A., KIRKHAM, F. & McCRACKEN, D. 2007. Management of agricultural grassland to promote in-field structural heterogeneity, invertebrates and birds in pastoral landscapes. *In:* J.J.Hopkins, eds. *High Value Grassland: providing biodiversity, a clean environment and premium products.* Occasional Symposium No.38, 289-292. Cirencester: British Grassland Society.

PEARCE-HIGGINS, J. W. & GRANT, M. C. 2006. Relationships between bird abundance and the composition and structure of moorland vegetation. *Bird Study*, 53, 112-125.

PINCHES, C. & RIMES, C. 2007. *The state of species-rich lowland grassland in the UK: Problems at the grass roots.* In: High Value Grassland: Providing biodiversity, a clean environment and premium products. BGS Occasional Symposium No. 38.

PINCHES, C., GOWING, D., STEVENS, C., FAGAN, K. & BROTHERTON, P. 2013. Natural *England review of upland evidence 2012 – Upland Hay Meadows: what management regimes maintain the diversity of meadow flora and populations of breeding birds?* Natural England Evidence Review, Number 005. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/5969921**

PLASSMANN, K., JONES, M. L. M. & EDWARDS-JONES, G. 2010, Effects of long-term grazing management on sand dune vegetation of high conservation interest. *Applied Vegetation Science*, 13: 100–112. doi: 10.1111/j.1654-109X.2009.01052.x

POLÁKOVÁ, J., TUCKER, G., HART, K., DWYER, J. & RAYMENT, M. 2011. *Addressing biodiversity and habitat preservation through Measures applied under the Common Agricultural Policy.* Report Prepared for DG Agriculture and Rural Development, Contract No. 30-CE-0388497/00-44. London: Institute for European Environmental Policy.

PYWELL, R.F, BULLOCK, J.M., PAKEMAN, R.J., MOUNTFORD, J.O., WARMAN, E.A., WELLS, T.C.E & WALKER, K. 1995a. *Review of calcareous grassland and heathland management.* Report for MAFF. MAFF/NERC contract, Abbots Ripton. URL: **http://nora.nerc.ac.uk/504619/1/O148714CR.pdf**

PYWELL, R.F., BULLOCK, J.M., TALLOWIN, J.R.B., WALKER, K.J., WARMAN, E.A. & MASTERS, G. 2007. Enhancing diversity of species poor grasslands: an experimental assessment of multiple constraints. *Journal of Applied Ecology*, 44, 81-94.

PYWELL, R.F., HEARD, M.S., BRADBURY, R.B., HINSLEY, S., NOWAKOWSKI, M., WALKER, K.J. & BULLOCK, J.M. 2012. *Wildlife-friendly farming benefits rare birds, bees and plants.* Biology letters. Published online 6 June 2012 doi: 10.1098/rsbi.2012.0367

PYWELL, R.F., WEBB, N.R. & PUTWAIN, P.D. 1994. Soil fertility and its implications for the restoration of heathland on farmland in southern Britain. *Biological.Conservation,* 70, 169-181.

PYWELL, R.F., WEBB, N.R. & PUTWAIN, P.D. 1995b. A comparison of techniques for restoring heathland on abandoned farmland. J. Appl. Ecol. 32, 400-411.

READ, H.J. 2000. *Veteran tree management handbook.* Peterborough: English Nature. URL: **http://publications.naturalengland.org.uk/publication/75035**

READ, D.J., FREER-SMITH, P.H., MORISON, J.I.L., HANLEY, N., WEST, C.C. & SNOWDON, P.R. 2009. *Combating climate change – a role for UK forests.* Edinburgh: The Stationery Office.

ROBERTS, P.D. & PULLIN, A.S. 2007. *The effectiveness of land-based schemes (incl. agri-environment) at conserving farmland bird densities within the UK.* Systematic Review No. 11. Collaboration for Environmental Evidence. Birmingham: Centre for Evidence-Based Conservation.

ROBINSON, D.A., COOPER, D., EMMETT, B.A., EVANS, C.D., KEITH, A., LEBRON, I., LOFTS, S., NORTON, L., REYNOLDS, B., TIPPING, E., RAWLINS, B.G., Tye, A.M., WATTS, C.W., WHALLEY, W.R., BLACK, H.I.J., WARREN, G. P., ROBINSON, S., MICHAELIDES, K. & HOCKLEY, N.J. 2008. *Defra Soil Protection Research in the Context of the Soil Natural Capital / Ecosystem Services Framework.* Centre for Ecology and Hydrology: Report to Defra for Project SP1607: Synthesis of Soil Protection work 1990-2008.

ROTAP. 2012. *Review of Transboundary Air Pollution, Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK.* URL: **www.rotap.ceh.ac.uk**

SEYMOUR, S., COX, G. & LOWE, P. 1992. *Nitrates in Water: The Politics of the 'Polluter Pays Principle'*. Sociologia Ruralis*,* 32 (1).

SHEPHERD, M., LABADZ, J., CAPORN, S., CROWLE, A., GOODISON, R., REBANE, M. & WATERS, R. 2013. *Natural England review of upland evidence – Restoration of degraded blanket bog.* Natural England Evidence Review, Number 002. Sheffield: Natural England. URL: **http://publications.naturalengland.org.uk/publication/5724597**

SIBBALD, A. M., OOM, S. P., HOOPER, R.J. & ANDERSON, R. 2008. Effects of social behaviour on the spatial distribution of sheep grazing a complex vegetation mosaic. *Applied Animal Behaviour Science*, 115, 149-159.

SKINNER, J.A., LEWIS, K.A., BARDON, K.S., TUCKER,P., CATT, J.A. & CHAMBERS, B.J. 1997. An overview of the impact of agriculture in the UK. *Journal of Environmental Management,* 50, 111-128.

SMART, J., WOTTON, S.R., DILLON, I.A., COOKE, A.I., DIACK, I., DREWITT, A.L., GRICE, P.V., & GREGORY, R.D. 2014. Synergies between site protection and agri-environment schemes for the conservation of waders on lowland wet grasslands. *Ibis,* 156: 576–590. doi: 10.1111/ibi.12153

SMART, S., MASKELL, L.C., DUNBAR, M.J., EMMETT, B.A., MARKS, S., NORTON, L.R., ROSE, P., SCHOLEFIELD, P.A., HENRYS, P. & SIMPSON, I.C. 2010. *An Integrated Assessment of Countryside Survey data to investigate Ecosystem Services in Great Britain*. Centre for Ecology and Hydrology CS Technical Report 10/07.

SMITH, R.S. 2010. Understanding grassland systems. *In:* D. GAMBLE & T. ST. PIERRE, eds. *Hay Time: the natural, cultural & land management history of hay meadows in the Yorkshire Dales.* pp 145-177. Clapham: Yorkshire Dales Millennium Trust.

STEVENS, C.J., SMART, S.M., HENRYS, P.A., MASKELL, L.C., WALKER, K.J., PRESTON, C.D., CROWE, A., ROWE, E.C., GOWING, D.J. & EMMETT, B.A. 2011. *Collation of evidence of nitrogen impacts on vegetation in relation to UK biodiversity objectives.* JNCC Report, No. 447. URL: **http://jncc.defra.gov.uk/page-5894**

STEVENS, P. & WILSON, P. 2012. Species-rich grassland re-creation projects. A route to success? *Aspects of Applied Biology,* 115, 53-60.

STEWART, G.B., COLES, C.F. & PULLIN, A.S. 2004a. *Does burning degrade blanket bog?* Systematic Review No. 1. Collaboration for Environmental Evidence.

STEWART, G.B., COLES, C.F. & PULLIN, A.S. 2004b. *Does burning of UK sub-montane, dry dwarf-shrub heath maintain vegetation diversity?* Systematic Review No. 2. Collaboration for Environmental Evidence. Sheffield: Natural England.

STEWART, G.B. & PULLIN, A.S. 2006. *Does sheep-grazing degrade unimproved neutral grasslands managed as pasture in lowland Britain?* Systematic Review No. 15. Collaboration for Environmental Evidence. Sheffield: Natural England.

STEWART, G.B., TYLER, C. & PULLIN, A.S. 2005. *Effectiveness of current methods for the Control of Bracken (Pteridium aquilinum).* Systematic Review No. 3. Collaboration for Environmental Evidence. Sheffield: Natural England.

SYMES, N. & DAY, J. 2003. *A practical guide to the restoration and management of lowland heathland.* Sandy: RSPB.

TOWNSHEND, D., STACE, H. & RADLEY, D. 2004. *State of nature: Lowlands – future landscapes for wildlife.* Peterborough: English Nature.

UK NATIONAL ECOSYSTEM ASSESSMENT. 2011. *The UK national ecosystem assessment technical report.* Cambridge, UNEP-WCMC.

UK TECHNICAL ADVISORY GROUP ON THE WATER FRAMEWORK DIRECTIVE. 2014. Technical report on groundwater dependent terrestrial ecosystem (GWDTE) threshold values. URL: **www.wfduk.org/sites/default/files/Media/Environmental%20standards/WTT%20technical%20report%20on%20wetland%20chemical%20threshold%20values%20final_v9.pdf**

VAN DER WAL, D., PEARCE, I., BROOKER, R., SCOTT, D., WELCH, D. & WOODIN, S. 2003. Interplay between nitrogen deposition and grazing causes habitat degradation. *Ecology Letters*, 6, 141-146.

VAN DER WAL, R., BONN, A., MONTEITH, D., REED, M., BLACKSTOCK, K., HANLEY, N., THOMPSON, D., EVANS, M. & ALONSO, I. 2011. Mountains moorlands and heaths. *In: The UK National Ecosystem Assessment Technical Report.* pp 105–158. UK National Ecosystem Assessment. Cambridge: UNEP-WCMC.

WALKER, K.J., PYWELL, R.F., WARMAN, E.A., FOWBERT, J.A., BHOGAL, A. & CHAMBERS, B.J., 2004. The importance of former land use in determining successful re-creation of lowland heath in southern England. *Biological. Conservation,* 116, 289-303.

WALKER, K.J., WARMAN, E.A., BHOGAL, A., CROSS, R.B., PYWELL, R.F., MEEK, B.R., CHAMBERS, B.J. & PAKEMAN, R. 2007. Recreation of lowland heathland on ex-arable land: assessing the limiting processes on two sites with contrasting soil fertility and pH. *Journal of Applied Ecology,.* 44, 573-582.

WATERS, R. D., LUSARDI, J., & CLARKE, S. 2012. *Delivering the ecosystem approach on the ground – an evaluation of the upland ecosystem service pilots.* Natural England Research Reports, Number 046. URL: **http://publications.naturalengland.org.uk/publication/4084624**

WEBB, J.R., DREWITT, A.L. & MEASURES, G.H. 2010. *Managing for species: Integrating the needs of England's priority species into habitat management.* Part 1 Report Natural England Research Report NERR024. Sheffield: Natural England. URL:
http://publications.naturalengland.org.uk/publication/30025

WEBB, N.R., 1989. Studies on the invertebrate fauna of fragmented heathland in Dorset, UK, and the implications for conservation. *Biological. Conservation,* 47, 153-165.

WEBB, N.R. & THOMAS, J.A. 1994. Conserving insect habitats in heathland biotopes: a question of scale., *In*: Edwards, P.J., May, R. and Webb, N.R. (Eds.), *Large-Scale Ecology and Conservation Biology.* Blackwell Scientific Publications, Oxford, pp. 129-151.

WELCH, D. 1998. Response of bilberry *Vaccinium myrtillus* L stands in the Derbyshire Peak District to sheep grazing, and implications for moorland conservation. *Biological Conservation,* 83, 155-164.

WHEELER, B.D., SHAW, S.C. & TANNER, K. 2009. *A Wetland Framework for Impact Assessment at Statutory Sites in England and Wales.* Environment Agency Science Report: SC030232/SR1. Bristol: Environment Agency.

WHITTINGHAM, M. J. 2011. The future of agri-environment schemes: biodiversity gains and ecosystem service delivery? *Journal of Applied Ecology*, 48, 509-513.

WINSPEAR, R., GRICE, P., PEACH, W., PHILLIPS, J., AEBISCHER, N., THOMPSON, P., EGAN, J. & NOWAKOWSKI, M. 2010. The development of Farmland Bird Packages for arable farmers in England. *Aspects of Applied Biology*, 100, 347-352.

WORRALL, F., CHAPMAN, R., HOLDEN, J., EVANS, C., ARTZ, R., SMITH, P. & GRAYSON, R. 2010. *Peatlands and Climate Change.* IUCN Commissioned Review. URL: **www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/Review%20Peatlands%20and%20Climate%20Change,%20June%202011%20Final_0.pdf**

WYBORN, C. & BIXLER, R. P. 2013. *Collaboration and nested environmental governance: Scale dependency, scale framing and cross-scale interactions in collaborative conservation*. *Journal of Environment Management,* 123, 58-67.

ZHANG, H. & HISCOCK, K. M. 2011. Modelling the effect of forest cover in mitigating nitrate contamination of groundwater: A case study of the Sherwood Sandstone aquifer in the East Midlands, UK. *Journal of Hydrology*, 399, 212-225.

Further information

Natural England evidence publications can be downloaded from the publications and products catalogue: **http://publications.naturalengland.org.uk/**. In particular see **Natural England summaries of evidence**. For information on Natural England evidence publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

Author

Author: Steve Chaplin **stephen.chaplin@naturalengland.org.uk**

We welcome your comments on this summary. Please send them to the author at the above address.

Copyright

ISBN 978-1-78354-169-0