Natural England Research Report NERR026

Carbon Management by Land and Marine Managers

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Carbon Management by Land and Marine Managers

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Preface

England’s soils, vegetation and coastal systems store significant amounts of carbon and play a vital role in regulating our climate. By helping to protect these ecosystems from degradation and loss, land and marine managers can help mitigate the causes of climate change.

Summary

Terrestrial and marine ecosystems are a major reservoir of carbon, being integral components of the global carbon cycle. Significantly more carbon is stored in soils, vegetation and the oceans than in the atmosphere, and these carbon stores play a vital role in regulating the climate.

Land and marine managers can help to protect and secure carbon stores in soils, vegetation and the oceans, as well as enhance sequestration. However, in some cases degraded habitats can lose significant amounts of carbon and so contribute to the causes of climate change.

This report is a wide-ranging review of the scientific evidence on how land and marine managers can protect carbon stores and enhance carbon sequestration. Focussing on five key ecosystems - peatlands, woodlands, agricultural soils, coasts and marine, the report aims to:

- Assess how much CO_2 and other greenhouse gases are emitted and stored according to the way each ecosystem is used and managed in England.
- Determine how land and marine managers can protect and enhance natural carbon stores.
- Identify the priorities for further research.
- Review the potential for land and marine managers to engage with the emerging carbon market.

Key findings

This review has identified five key findings:

1) **Peatlands are England's most important carbon store**. However peatlands also emit significant amounts of CO_2 when they are degraded. This report has estimated that in England's lowland fens alone, degraded peatlands could release between **2.8 and 5.8 million tonnes** of CO_2 each year. This is significantly higher than is currently recorded in the UK's formal Greenhouse Gas Inventory, which does not even account for any further potential carbon losses from degraded peat bogs in England's uplands.
2) **Peatland restoration will reduce carbon losses**. However, there is a need for more information on how much methane is emitted from restored peatland sites. Methane is a more potent greenhouse gas than carbon dioxide and will reduce or counteract carbon savings in some situations. More research is needed to establish the greenhouse gas benefits of restoration before carbon revenues could be generated on a large scale.
3) **Woodlands make the most important contribution to CO_2 sequestration in the UK**. The evidence suggests that bringing neglected woodlands into management for bio-energy and low-carbon products will deliver more carbon benefits than widespread tree planting. New markets for wood products could also generate additional income streams for farmers while increasing biodiversity.
4) **Increasing carbon storage in agricultural soils has limited potential**. Practices that could make a contribution include changing tillage (for example adopting farming techniques where the land is not ploughed or turned), increasing organic returns (applying farmyard manure and other organic matter to increase the soil's organic carbon) and taking some land out of cultivation (including allowing buffer strips at the edges of fields). However, the evidence that permanent greenhouse gas benefits can be gained from such changes is weak. Consideration of the extent to which food production could be displaced also needs to be taken into account.
5) **Coastal and marine ecosystems are vital global carbon stores**. However, we do not currently have sufficiently strong evidence on the carbon benefits from maintaining,

restoring and creating these habitats. More research is required before this potential can be quantified.

Plate i Bog species - Moorthwaite

Peatlands

Over the past 10,000 years peatlands have sequestered significant amounts of CO_2 from the atmosphere and as such have become important carbon stores. The amount of carbon stored in the UK's peatlands (5.5 billion tonnes) dwarfs the total stored in woodlands (150 million tonnes). However, peatlands can also lose carbon if they are in a degraded condition.

This report estimates that English lowland peatlands could be emitting between 2.8 and 5.8 million tonnes of CO_2 a year, which exceeds higher profile sources, such as domestic aviation (2.47 $MtCO_2$) and is on a level with emissions from UK cement production (5.42 $MtCO_2$). This figure is significantly higher than the 1.15 million tonnes of CO_2 recorded in the UK's Greenhouse Gas Inventory. This discrepancy is due to the UK Inventory under-estimating the area of deep peatlands.

Restoration of the hydrology of damaged peatlands will reduce losses of CO_2, but this practice is also likely to increase methane emissions. However, studies of a limited number of restored peatlands across Europe suggest that restoration will generally deliver a net greenhouse gas benefit, despite increasing methane emissions, due to the scale of CO_2 savings.

More research is required on the impact of restoration on methane emissions from different peatlands to establish the GHG (greenhouse gases) benefits of restoration, before these can be used to generate income from trading emissions savings on a wide scale.

Woodlands

Woodlands have a vital contribution to make to climate mitigation, achieved primarily through improving their management and realising the potential of the existing resource, much of which is neglected. Bringing farm woodlands back into viable economic production through developing new markets for woodfuel and wood products will deliver greenhouse gas savings through reduced use of fossil fuels, enhance woodland sequestration and deliver a wide range of other environmental, social and economic benefits.

Agricultural croplands and grasslands

Land managers can increase carbon storage in mineral agricultural soils, through practices such as changing tillage, increasing organic returns and taking some land out of active cultivation (for example, buffer strips).

However, the evidence for the permanent greenhouse gas benefits delivered from such management changes is relatively weak and often inconclusive. There are also other considerations, such as displacement of production, which could negate any greenhouse gas benefits.

Coasts and marine

Coastal habitats, such as saltmarsh, are already recognised as playing an important role in nutrient recycling including for carbon. However, these important habitats are vulnerable both to the direct impacts of climate change (ie from sea level rise) and in some cases to insensitive management and engineered flood risk responses. There is a lack of evidence on the current scale of carbon storage in UK coastal habitats and a need to develop robust emission factors that will quantify the greenhouse gas benefits from coastal habitat restoration and creation projects.

The potential from marine sequestration is vast, but not enough is known at the moment to develop any form of carbon management scheme. Effort needs to be directed towards bringing the evidence base together and more research is required.

Next steps

Carbon management by land and marine managers could deliver significant benefits for climate change mitigation and the provision of a range of ecosystem services. It also offers potential new market opportunities for those who manage England's land and marine systems. However, to realise these opportunities in full, the following actions need to be taken:

Develop the evidence base

- The gaps in our understanding need to be bridged. A comprehensive research programme is needed. This should focus initially on UK peatlands.

Engage with the carbon markets

- We need to develop methodologies so that it is possible to verify the carbon savings from projects that restore or enhance carbon stores. These projects will also have to demonstrate that they are additional (i.e. would not have taken place without carbon funding.

Raise the profile of carbon stores

- It is important for policy makers to understand the potential contribution that carbon stores can make to climate change mitigation while also delivering other benefits.

Integrate land use in carbon accounting

- Ensure that carbon accounting tools include emissions from land use and land use change, so that land managers are aware of the carbon implications and opportunities of different management practices.

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1 Introduction

Scope of report

1.1 Land and marine managers can make an important contribution to action on the causes of climate change in three broad ways (Smith and others, 2007):

1) Reducing direct greenhouse gas emissions from land and livestock management and energy use.
2) Enhancing sequestration of CO_2 from the atmosphere by carbon sinks and securing carbon stored in soils, vegetation and marine ecosystems.
3) Avoiding/displacing emissions, for example reducing fossil fuel consumption by providing bio-energy sources.

1.2 The Agricultural, Forestry and Land Management (AFLM) sector accounts for approximately 7% of the UK's total greenhouse gas emissions. It is responsible for emitting three major greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

1.3 Agriculture is the single largest source of nitrous oxide (67% of UK's N_2O emissions), which primarily comes from the application of artificial fertilisers, from livestock manure and from leaching. The sector is also a major source (37%) of the UK's methane emissions, which are mostly from manure and enteric fermentation by livestock. AFLM is a relatively small emitter of CO_2 from energy use compared to other sectors of the economy being responsible for just under 5 million tonnes of CO_2 in 2006, around 0.7% of total UK CO_2 emissions (Choudrie and others, 2008).

1.4 Land use and land use change also cause CO_2 emissions, mainly from the loss of soil organic carbon to the atmosphere from cultivation, drainage and degradation. Over 22 million tonnes of CO_2 was emitted in 2006 from land use and land use change (Choudrie and others, 2008).

1.5 However, land and marine managers are also uniquely able to enhance the ability of soils, vegetation and marine ecosystems to sequester CO_2. Forestry and land use change to grasslands sequestered just under 25 million tonnes in 2006. This meant that overall, land use, land use change and forestry (LULUCF) was a small net sink, directly reducing the UK's overall CO_2 emissions by around 2 million tonnes, or 0.4%.

1.6 As well as being able to enhance CO_2 sequestration, land and marine managers are also the custodians of a significant carbon stores. Around 10 billion tonnes[1] is estimated to be stored in UK soils, equivalent to a year and a half of global carbon emissions. UK woodlands are also an important carbon store, although not as significant as soils, with around 150 million tonnes. It is clearly vital that the carbon stored in terrestrial and marine ecosystems is not lost in significant quantities to the atmosphere.

1.7 This report focuses on the contribution to climate mitigation that land and marine managers can make from enhancing sequestration by carbon sinks and securing the carbon stored in terrestrial in marine ecosystems. This includes reviewing how land managers can help reduce CO_2 emissions from land use, particularly soils.

[1] Note this is carbon, not carbon dioxide. To convert carbon to CO_2 multiply by 3.66

Objectives of report

1.8 The report aims to:

1) Review the scientific understanding of the amount of carbon stored within the UK's terrestrial and marine ecosystems.
2) Assess the scale of current CO_2 (and other GHG) emissions and sequestration from LULUCF and marine management practices.
3) Identify LULUCF and marine management practices that can reduce CO_2 emissions and /or enhance sequestration and assess their implications for the natural environment.
4) Review the potential for LULUCF and marine management projects to engage with the emerging carbon market.
5) Identify the priorities for further research.

1.9 Research into this area is expanding at a considerable rate. This report will attempt to include the most up to date evidence at the time of publication.

Intended audience

1.10 This report is aimed primarily at policy makers, academics, practioners from the land and marine management sector, non-governmental organisations and the interested public.

1.11 It is not intended, at this stage, to form specific guidance to land and marine managers at an operational or delivery level.

2 Accounting for carbon

Global carbon cycle

2.1 The global carbon cycle can be viewed as a four-compartment system that comprises terrestrial (soils and vegetation), atmospheric, oceanic and deposited (fossil fuel) carbon pools, with flows connecting each pool with all others.

2.2 Vegetation and soils sequester CO_2 from the atmosphere by photosynthesis, of which around half is returned immediately by plant respiration. The remaining carbon, over a longer time period, ends up as litter which enters the decomposer system, and becomes transformed into soil organic matter. Eventually the vast majority will be recycled back into the atmosphere through processes such as respiration by soil organisms, decomposition, erosion into watercourses, fire, harvest and disturbance (Dawson & Smith, 2007).

2.3 In most cases, terrestrial and marine carbon sinks will eventually reach a point where inputs of CO_2 balance with outputs, and no further CO_2 will be sequestered from the atmosphere (Smith, 2005)."It then becomes a 'store' rather than a 'sink'. Once removed, carbon will be retained in stores for hundreds (even thousands) of years if it is undisturbed and the land management regime unchanged.

2.4 However, if a carbon store is damaged or disturbed then significant amounts of CO_2 (as well as other greenhouse gases) can be rapidly emitted to the atmosphere either directly as a gaseous flux, or indirectly through being dissolved in water courses (termed Dissolved Organic Carbon, DOC).

2.5 Historic and current human activity has contributed to the significant degradation of global terrestrial carbon stores. The starkest recent examples are the extensive deforestation of tropical rainforest and the drainage of wetlands. Such land use changes are the second largest global source of GHG emissions contributing 18% of CO_2 emissions and 25-30% of total GHG emissions[2] (Stern 2006).

2.6 Several major terrestrial carbon stores are vulnerable to climate change and/or land-use impacts. At a global scale, the terrestrial biosphere currently serves as a variable, but generally increasing carbon sink but this is likely to peak before mid century and then tend towards a net source before 2100 (IPCC, 2007). This weakening of terrestrial carbon sinks could alone amplify global warming by 1.5C this century (Stern, 2006). In Europe, the total terrestrial carbon sink strength is projected to decline over time with significant decreases in soil organic carbon in all climate change and land use scenarios (Zaehle, 2007).

National GHG inventories

2.7 Those countries who have signed the United Nations Framework Convention on Climate Change (UNFCCC) have to annually report all GHG emissions and sequestration from energy use, industrial processes, solvents, agriculture, LULUCF and waste. These reports are termed 'GHG Inventories' and are used to monitor annual global GHG emissions.

[2] Second only to greenhouse gas emissions from the energy sector (24%)

2.8 The Inter-Governmental Panel on Climate Change (IPCC) give guidance to countries on how to account for GHG emissions. This identifies a hierarchy of 'emission factors':

- Tier 1 - standard international default emissions factors.
- Tier 2 - country or regionally specific emissions factors.
- Tier 3 - detailed site/process specific data on emissions.

2.9 Emissions and sequestration from the management of terrestrial carbon sinks are recorded in national GHG inventories under the LULUCF sector. Emissions from other agricultural practices are recorded separately in the Agriculture section and include methane emissions from manure management and enteric fermentation and nitrous oxide emissions from soils, including peat. Emissions from agricultural energy use are recorded in the wider Energy section.

2.10 National inventories do not record marine emissions and sequestration and there is no process under the UNFCCC to account for emissions or sequestration caused by marine management practices.

2.11 The IPCC guidance sets out that LULUCF emissions and sequestration should be accounted for from the following land use categories:

- 5A Forestland
- 5B Croplands
- 5C Grasslands
- 5D Wetlands
- 5E Settlements.

2.12 The IPCC guidance has separate chapters for each land use category. Each chapter is further split in two, with guidance on accounting for land management practices which maintain current land use and guidance for accounting for emissions and sequestration from land use change. For example, the Cropland chapter has guidance on 'croplands remaining croplands' and on 'conversion to croplands'.

LULUCF and Kyoto

2.13 The national GHG inventories are used to monitor compliance for those countries who signed up to the Kyoto Protocol.

2.14 Kyoto allows for the accounting of some, but not all, LULUCF emissions and sequestration. Under Article 3.3, which is mandatory, emissions from deforestation and sequestration by afforestation and reforestation since 1990 are counted towards the emission reduction targets of Annex I countries[3]. In the UK, this has been interpreted on the basis of availability of verifiable, geo-referenced data to only include woodland planted under woodland grant schemes and/or directly by the Forestry Commission or Northern Ireland Forest Service.

2.15 Article 3.4 makes provision for the optional inclusion of emissions and sequestration from additional LULUCF activities relating to the improved management of existing forests, croplands and grasslands, restoration of degraded land and re-vegetation. It was agreed that there should be a cap on the contribution that sequestration from forest management can make to each country's emission reduction targets.

[3] Defined as industrialised nations who ratified the Kyoto Protocol

2.16 Of the Article 3.4 activities, the UK only accounts for sequestration from improved forest management towards its Kyoto commitment. Other Article 3.4 activities were not included in the first commitment period (2008-2012) due to uncertainties in measuring and verifying emissions and removals, as well as concerns that emission reductions and/or removals are not necessarily permanent and risk being reversed (for example through subsequent land use change, wildfire, etc).

UK LULUCF emissions and sequestration

2.17 LULUCF GHG emissions and sequestration as calculated in the UK inventory for 2006 are summarised in Table 1 below. Since 2004, the inventory data has also been reported in map format at the scale of Local Authority within the UK (Mobbs & Thomson, 2008).

Table 1a CO_2 emissions from UK LULUCF, 2006 (from Choudrie and others, 2008)

Land Use Category	Description	Emissions ($MtCO_2$)
5.B.1	Cropland remaining cropland - lowland fen drainage	1.151
5.B.1	Cropland remaining cropland - liming of agricultural soils	0.456
5.B.2	Land converted to croplands	14.311
5.C.1	Grasslands remaining grasslands - peat extraction	0.422
5.C.1	Grasslands remaining grasslands - liming of agricultural soils	0.313
5.E.2	Land converted to settlements	6.219
	Total	**22.872**

Table 1b CO_2 sequestration from UK LULUCF, 2006 (from Choudrie and others, 2008)

Land Use Category	Description	Sequestration ($MtCO_2$)
5.A.2	Land converted to forestland	15.112
5.B.1	Cropland remaining cropland	0.640
5.C.2	Land converted to grasslands	8.720
5.G	Other - harvested wood products	0.396
	Total	**24.868**

2.18 Overall, the LULUCF sector was a small net sink in 2006 (1.99 $MtCO_2$), effectively reducing the UK's total CO_2 emissions by around 0.4%.

LULUCF methodologies in UK GHG Inventory

2.19 The UK's inventory accounts for LULUCF using a mixture of Tier 1 methodologies based from the IPCC guidance and Tier 2/3 methodologies based on UK-specific data. The key methodologies used in the LULUCF section of the UK GHG Inventory (Choudrie and others, 2008) are summarised below.

Sequestration from forestland

2.20 The carbon uptake by forests planted since 1922 is calculated by a carbon accounting model, C-Flow (Cannell and others, 1992) as the net change in pools of carbon in standing trees, litter and soil for conifer and broadleaf forests and in products (Mobbs & Thomson, 2008). Forests accumulate carbon (sequestering it from the atmosphere) in their biomass and soils as they grow, but timber harvesting and planting activities disturb this accumulation and result in emissions. The net carbon stock change at any one time depends on the balance between these different activities.

2.21 About 65% of UK forests have been planted since 1920. The inventory assumes that forests in existence since before 1922 have reached equilibrium and so are no longer actively sequestering carbon.

2.22 The amount of carbon contained in woody biomass is calculated from the standing volume of usable timber, with the biomass expanded by a further factor to take into account branches and roots. The standing volume of usable timber is estimated from the recorded year of planting and Forestry Commission Yield Tables assuming conventional rotational forestry is practiced. As can be seen in Figure 1, the majority of UK sequestration from forestland occurs in Scotland and Wales.

2.23 For the purposes of Article 3.3 of Kyoto, the inventory also records sequestration from land converted to forest through grant-aid and/or direct Forestry Commission/NIFS planting after 1990.

Emissions from soils due to land use change

2.24 Changes from one land use type to another will result in a change in soil carbon stocks over time. The change in vegetation cover and management will affect the amount of carbon that goes into the soil from biomass decomposition. Also, the initial disturbance of the soil will release carbon to the atmosphere (Mobbs & Thomson, 2008). The inventory calculates changes in soil carbon levels caused by such land use change, which in turn gives a figure for net greenhouse gas emissions or sequestration for each land use category. The method for assessing changes in soil carbon stock due to land use change links a matrix of change from land surveys to a dynamic model of carbon stock change.

2.25 Annual changes in land use between the four IPCC categories are estimated using Countryside Survey data from 1984, 1990 and 1998. Land use in the UK was placed into the four broad IPCC categories (Forestland, Grassland, Cropland, and Settlements) by combining the more detailed categories of the Countryside Survey. Semi-natural habitats are generally included in the Grassland category. The UK has elected to not use the Wetland category.

2.26 A database of soil carbon density for the UK based on information on soil type, land cover and carbon content of soil cores has been available since 1995. These densities included carbon to a depth of 1m. For the 2003 Inventory a complete re evaluation of the database was carried out (Bradley and others. 2005). This database is used to estimate changes in soil carbon levels caused by each type of land use change.

2.27 In general, the development of settlements and conversion of land to arable production results in the loss of soil carbon and in turn carbon dioxide emissions. To illustrate, Figure 2 depicts the geographical variation of emission from land use change to croplands. Conversely, conversion of land to forest and grasslands from settlements or croplands delivers sequestration.

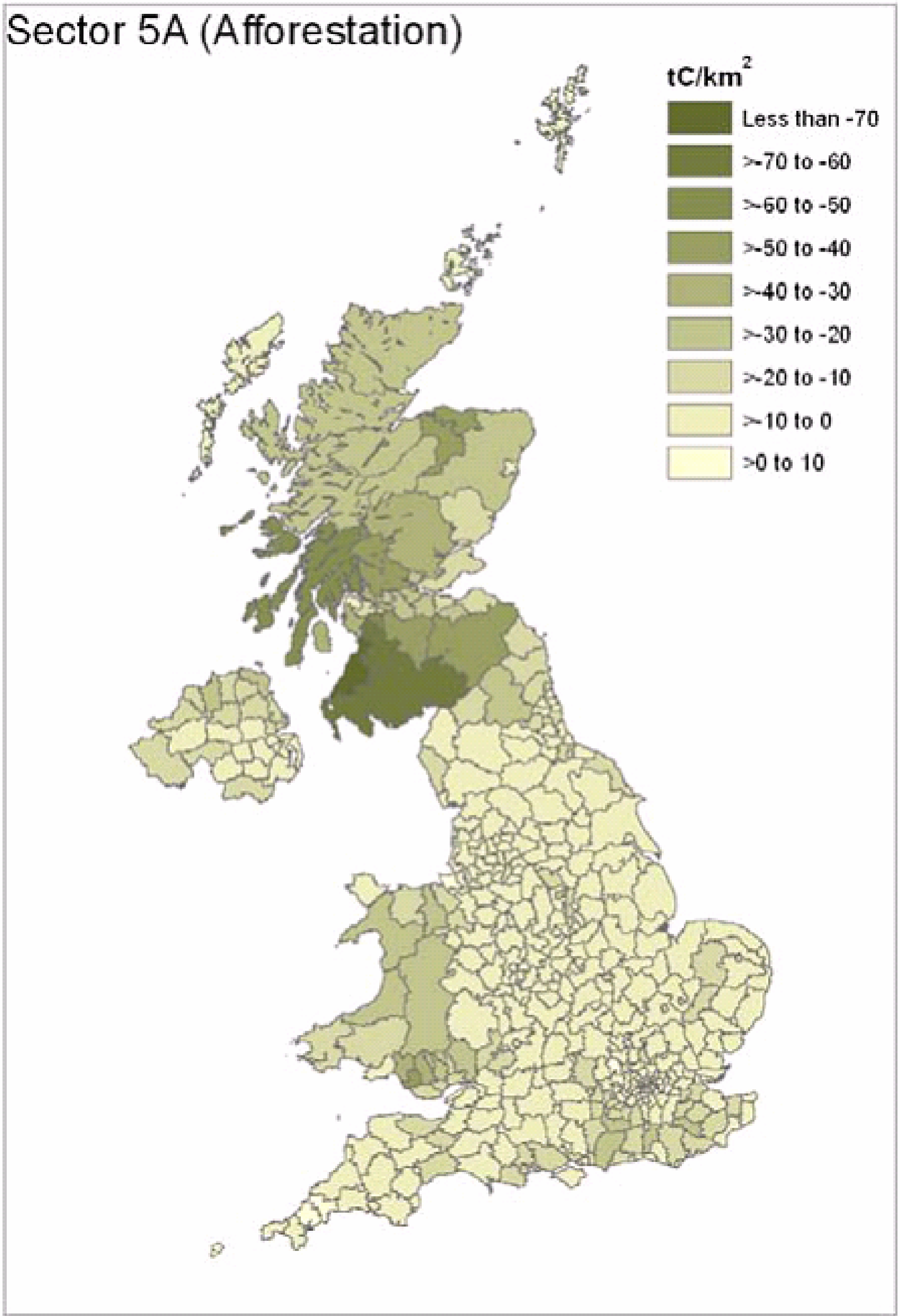

Figure 1 Distribution of carbon sequestration due to afforestation across the UK expressed as tC per km^2 (from Mobbs & Thomson, 2008)

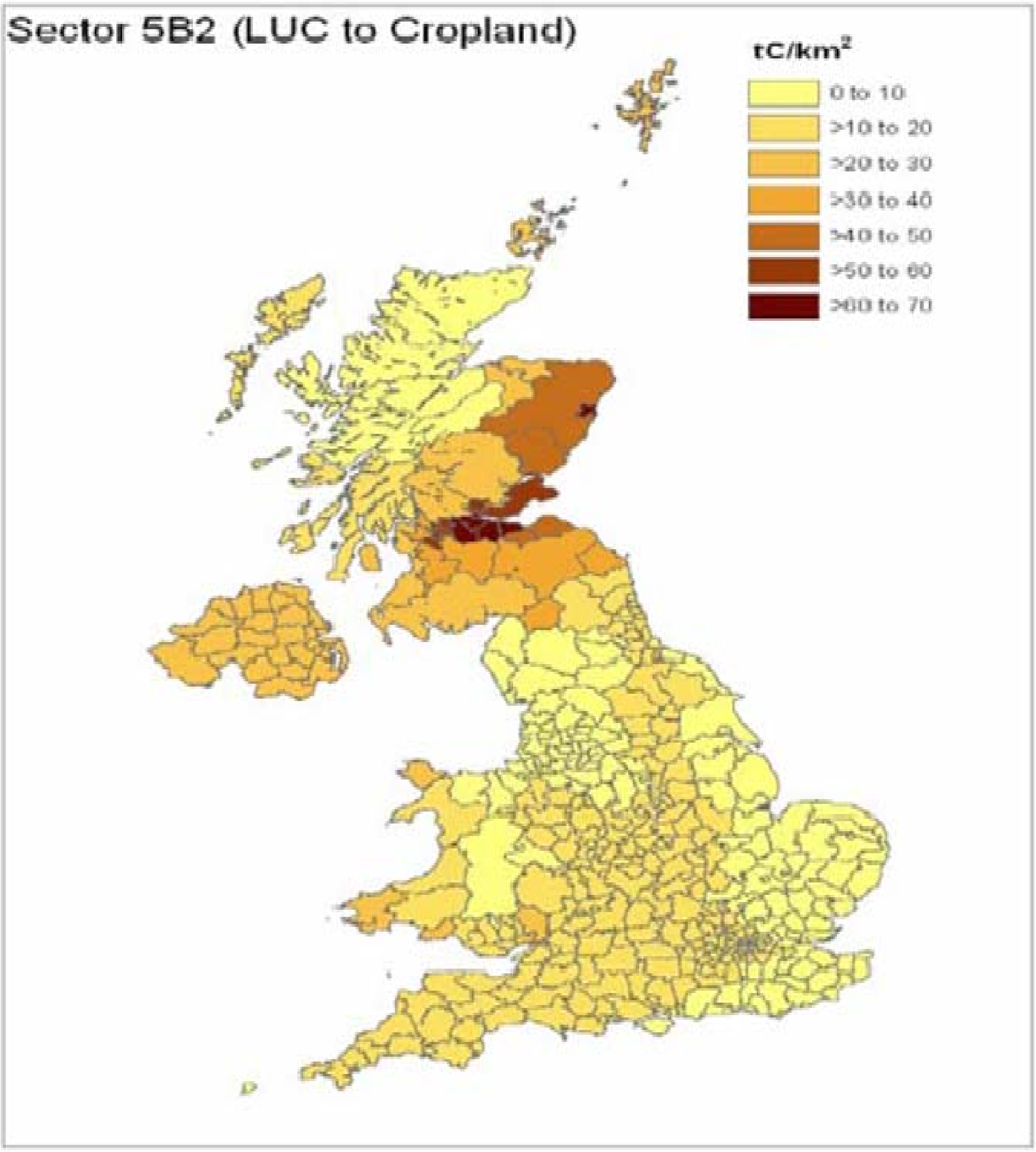

Figure 2 Carbon losses from soil due to land use change for conversion of all land types to croplands (tC/km^2)

Changes in stocks of carbon in non-forest biomass due to land use change

2.28 The different land use types have different biomass carbon densities at equilibrium. Change from one land use type to another can result in an increase or decrease in biomass carbon density. This category describes the annual change in the carbon stock in vegetation biomass due to all land use change to Grassland, Cropland or Settlements, excluding forests and woodland. This is estimated using the Countryside Survey Land Use Change matrix approach, with biomass densities weighted by expert judgement based on the work of Milne & Brown (1997).

Crop yield improvement

2.29 There is an annual increase in the biomass of cropland vegetation in the UK that is due to yield improvements (from improved species strains or management, rather than fertilization or nitrogen deposition). The increases in crop yield are calculated separately from those resulting from land use change.

Lowland peat drainage

2.30 Lowland wetlands in England were drained many years ago for agricultural purposes and continue to emit CO_2 from the soil. The Inventory takes a 1990 baseline for the area of drained lowland wetland for the UK as 150,000 ha. Figure 3 depicts the areas of the UK where the Inventory assumes there are CO_2 emissions from lowland peat drainage.

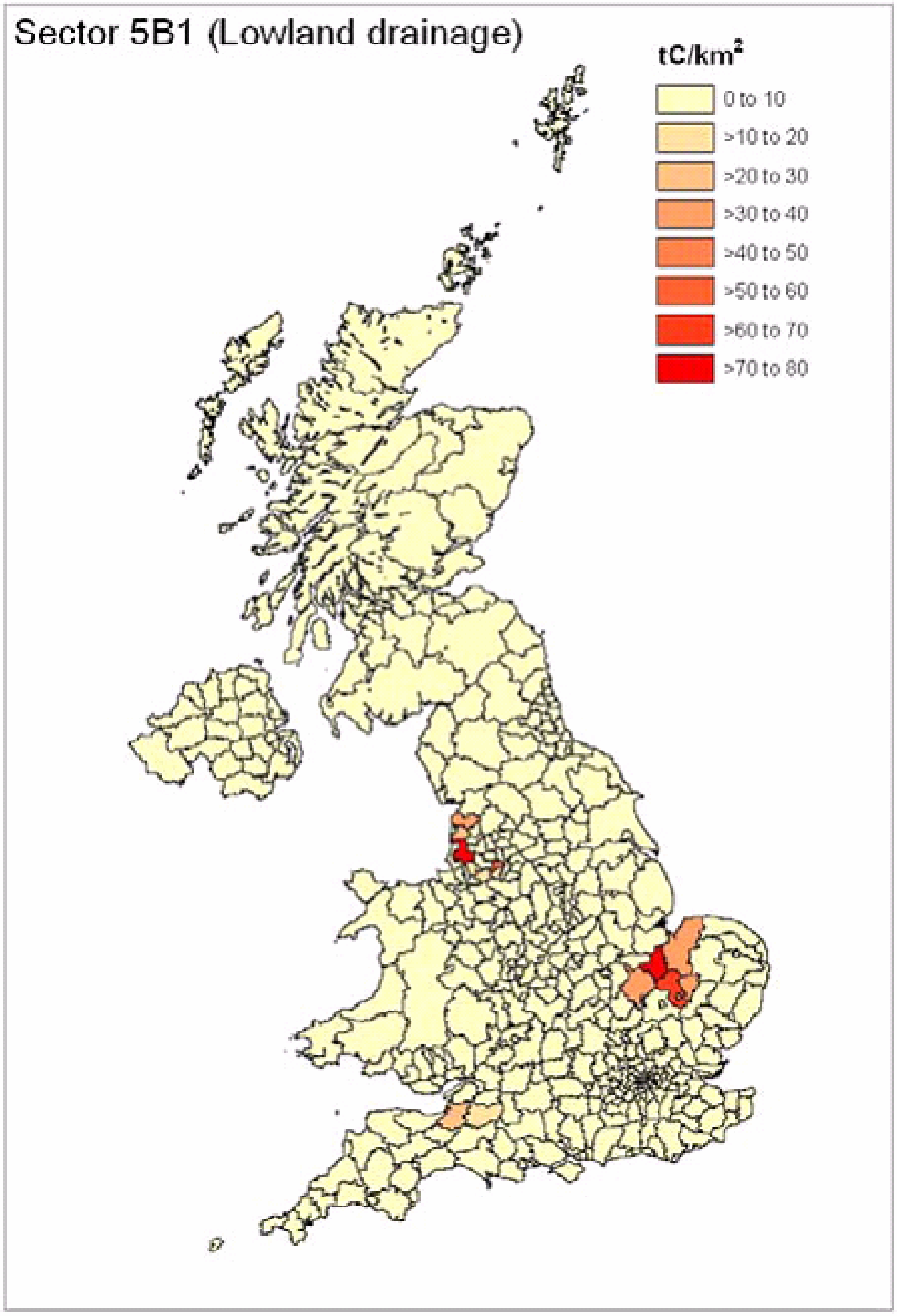

Figure 3 Carbon emissions in 2005 due to lowland drainage in previous years (tC/km^2)

2.31 This total consists of 24,000 ha of land with thick peat (more than 1m deep) and the rest with thinner peat. Different loss rates were assumed for these two thicknesses. The emissions trend since 1990 was estimated assuming that no more fenland has been drained since then but that existing drained areas have continued to lose carbon.

Peat extraction

2.32 Peat is extracted in the UK for use as either a fuel or in horticulture. The LULUCF section of the Inventory only accounts for horticultural use. Carbon emissions from peat extraction is calculated for the National Inventory based on data published in the *Mineral Extraction in Great Britain Business Monitor PA1007*. The data are also given for smaller regions, e.g. North East England, but not at the LA level. For mapping purposes, CEH have assumed that the data applies to all the LAs within the region in proportion to their area, as depicted in Figure 4.

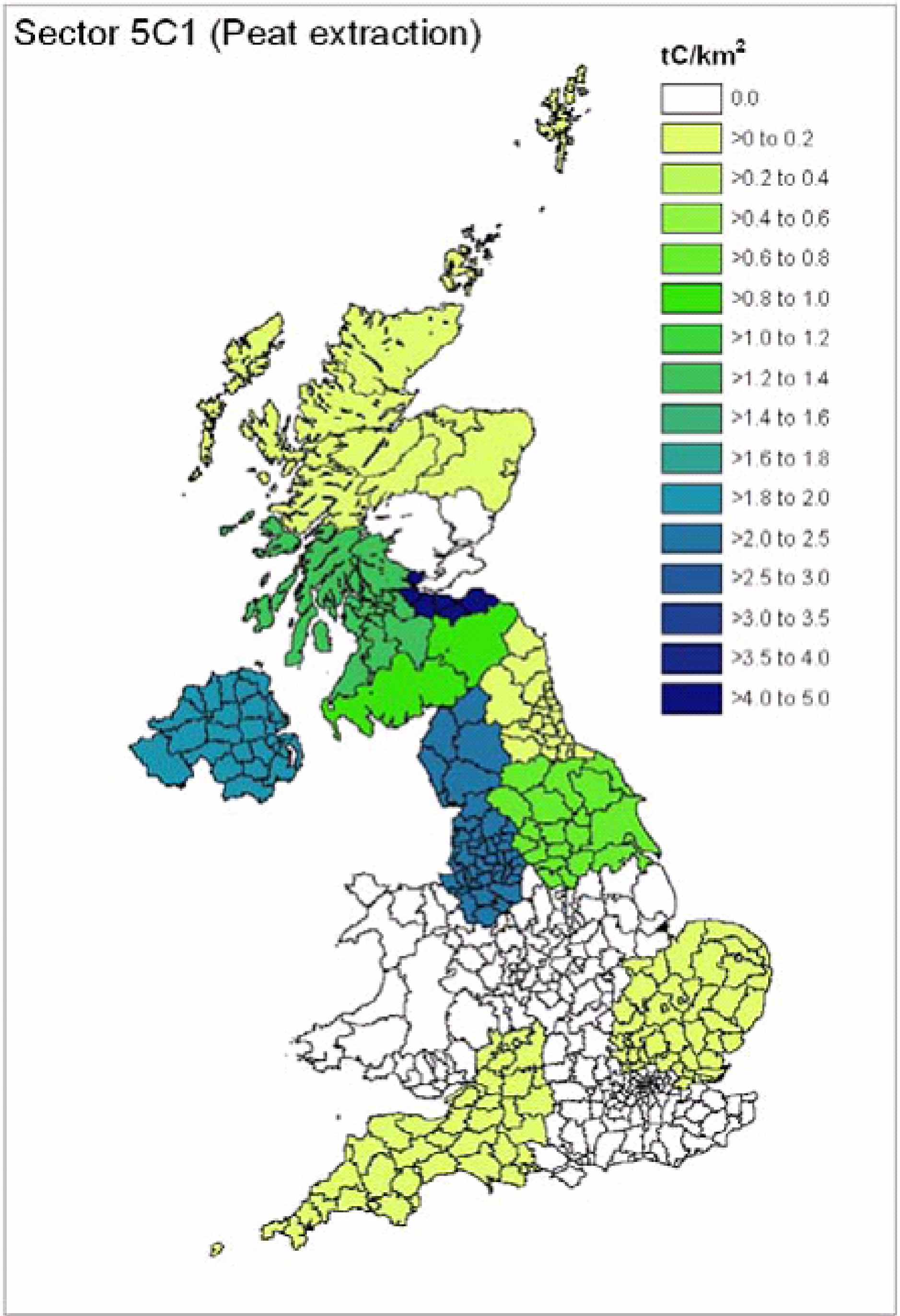

Figure 4 Carbon emissions resulting from the extraction of peat for horticultural use (tC/km^2)

Agricultural liming

2.33 The application of lime and related compounds to grasslands and cropland soils results in emissions of carbon dioxide. The annual percentages of arable and grassland areas receiving lime in Great Britain for 1994-2004 were obtained from the Fertiliser Statistics Report 2006. Figures 5 and 6 depict the geographical distribution of these emissions.

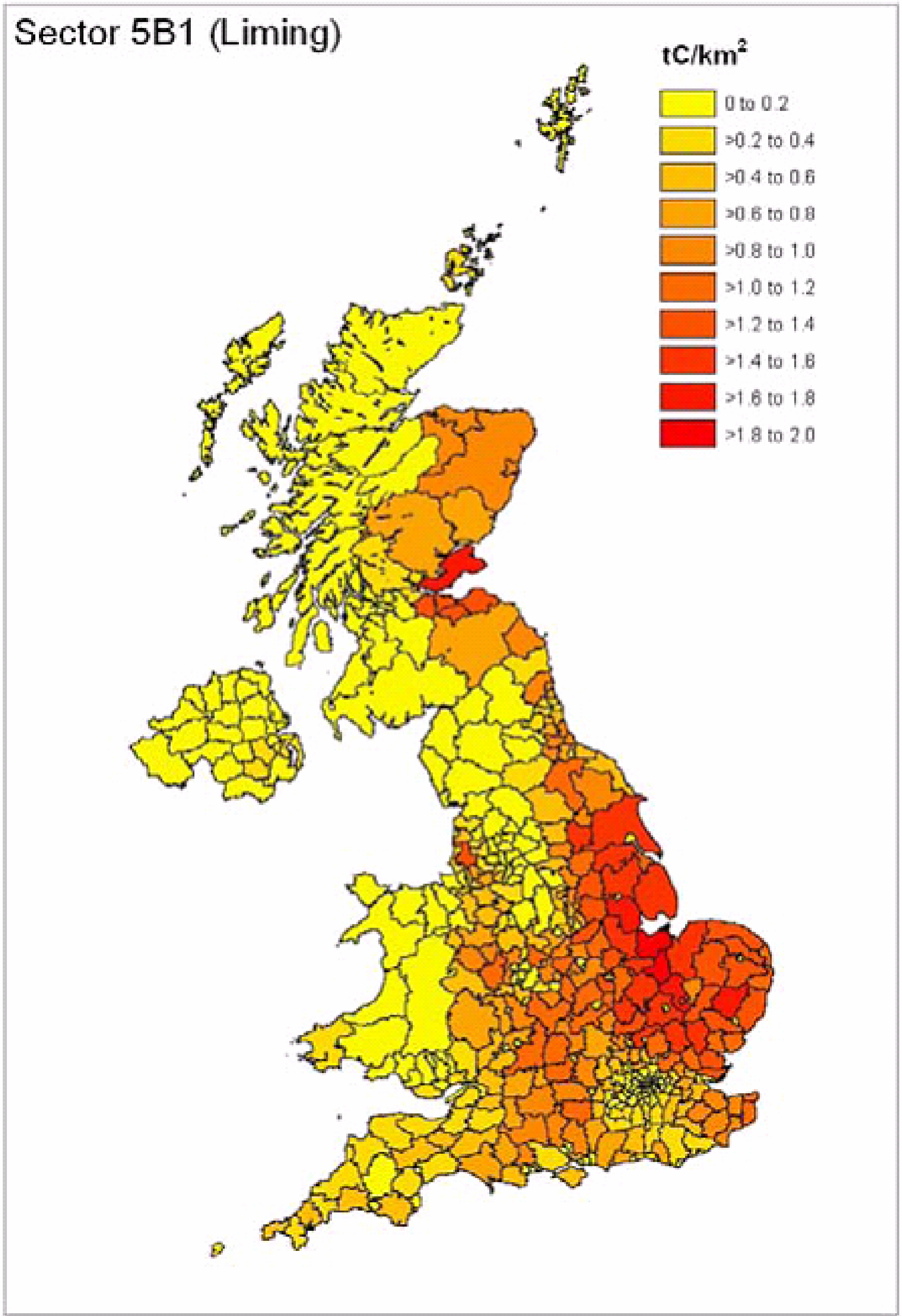

Figure 5 Carbon emissions due to liming of agricultural land (Cropland) (tC/km^2)

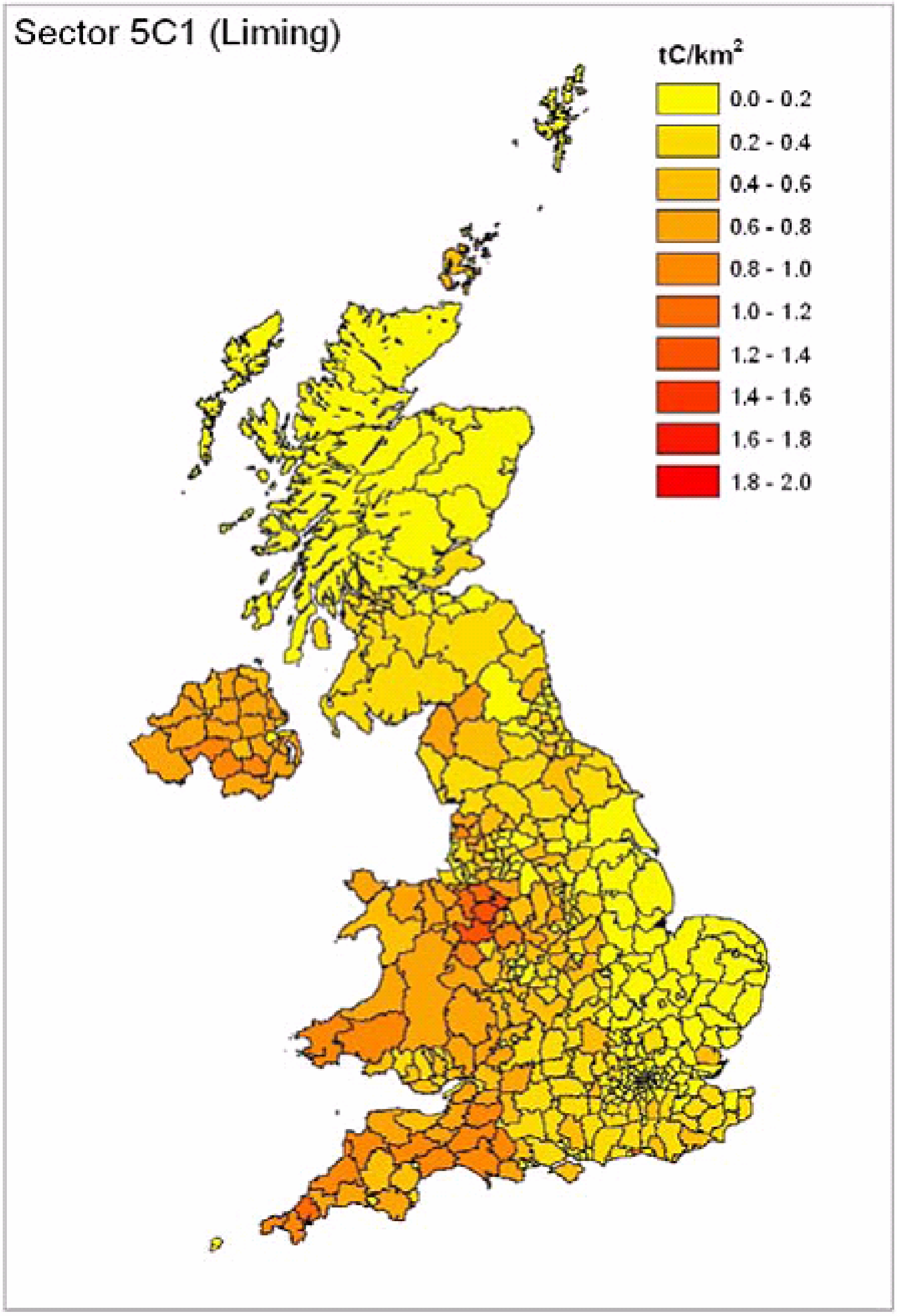

Figure 6 Carbon emissions due to liming of agricultural land (Grassland) (tC/km^2)

LULUCF emissions & sequestration by area

2.34 Figure 7 depicts total LULUCF emissions and sequestration at the LA scale for the UK. This shows that the majority of sequestration occurs in Scotland, Wales and Northern Ireland. There are some areas of England which record notably high levels of LULUCF emissions, mainly from lowland peat drainage.

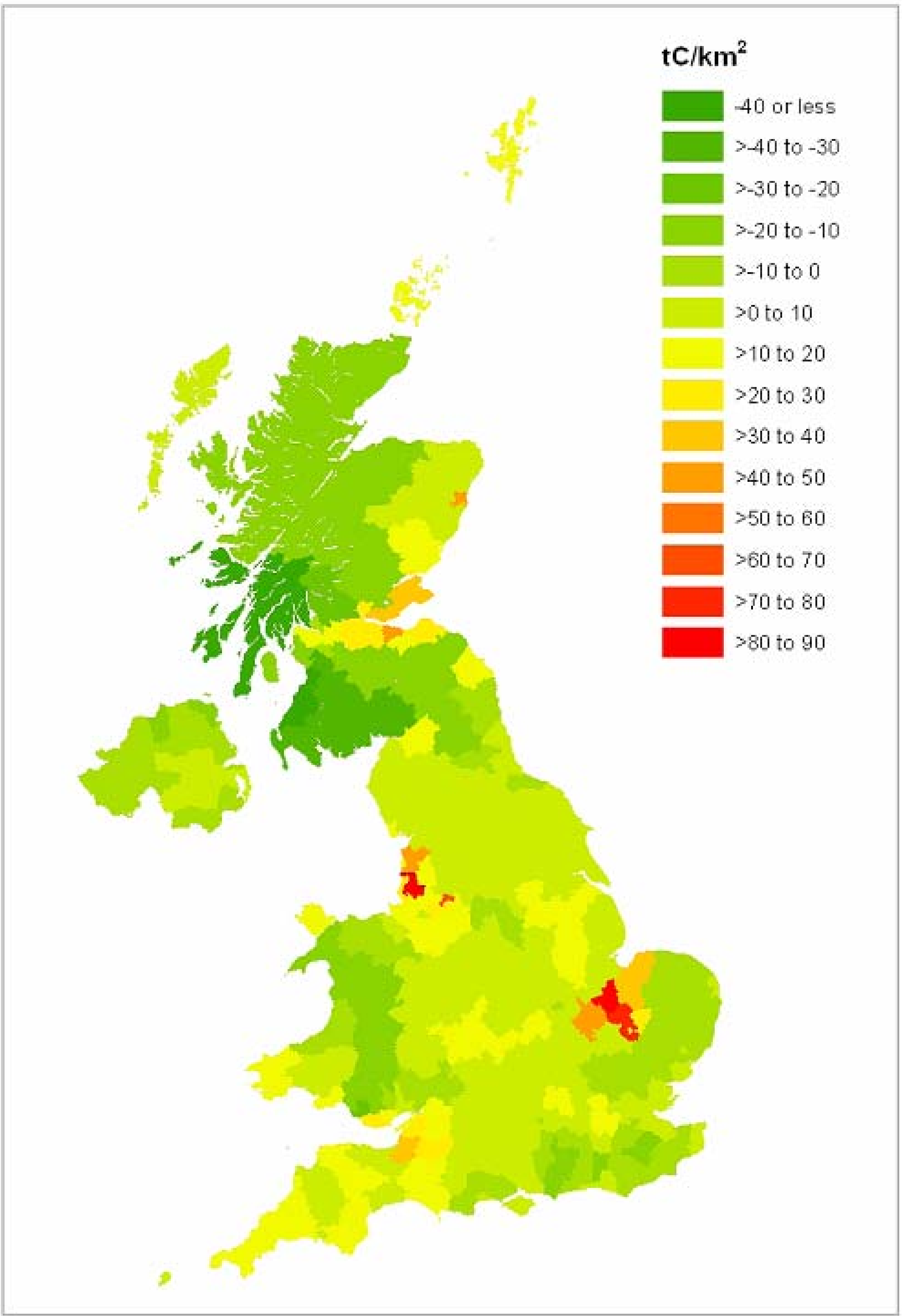

Figure 7 Total carbon emissions or sequestration for LULUCF across the UK (tC/km^2)

UK LULUCF projections

2.35 Projections for the LULUCF sector overall are that it will revert from being a small net sink to being a small net source of around 2 $MtCO_2$ by 2020 (UKCCP 2006). This is primarily because sequestration from forestland is declining due to falling woodland planting rates and the harvesting of woodland planted in the 1960s and 1970s (see Woodland section below for more detail).

3 Overview of the carbon market

3.1 Projects which deliver carbon benefits by securing carbon stocks and/or enhancing sequestration by terrestrial and marine ecosystems have the potential to earn 'carbon credits' from the emerging global carbon market. However, in order to ascertain this potential, it is necessary to firstly understand how carbon markets and carbon projects work.

Criteria for carbon projects

3.2 A key characteristic of the carbon market is the strict rules that have been developed for allowing projects which deliver emission reductions or sequestration to earn carbon credits. These rules are necessary to ensure that there is confidence in the integrity of the carbon market. In summary, they are (original source: UNFCCC, Kyoto Protocol. Digestible version from Carbon Trust, 2006):

Additionality

- The integrity of project-based credits relies on the reduction of emissions/sequestration beyond what would have occurred in a business-as-usual scenario. A project is additional if it is not required by current regulation, is not common practice and/or faces economic, investment or technological barriers that would prevent the implementation of the project.

Verification

- Monitoring and verification is essential to provide guarantees that the emissions reductions/sequestration claimed by a project have actually been achieved. To ensure the integrity of the verification process, emissions reductions/sequestration should always be verified by an accredited independent third party according to an established standard or methodology.

Permanence

- Refers to the ability of a project to maintain the reductions/sequestration achieved over time. Offset providers should offer some form of guarantee or insurance that ensures that the carbon credits contracted by a buyer are maintained over time.

Leakages

- A project must define and take into account leakages, defined as increases in emissions that take place beyond the project boundary and which are attributable to or a consequence of the project activity.

Double counting

- This could happen at a project level, when a credit is sold two or more times to different buyers or is rewarded through two different mechanisms (for example, through a grant scheme and then also with a carbon credit); and/or at a national level, where voluntary reductions are counted against national mandatory targets. To avoid the former, offset sellers should always have a registry in place where credits are accounted for and retired; without a registry in place, transactions cannot be logged or credited to buyers and potentially the same credit could be sold more than once. To guard against the second issue, rules that define how greenhouse gases are accounted for at a national level are required together with the use of national and international registries.

LULUCF projects

3.3 Demonstrating compliance with these criteria is particularly challenging for LULUCF projects. Emission reductions may not always be additional to what would have been achieved through ‘business as usual’ under existing legislative and good practice requirements, for example, through cross-compliance or Environmental Stewardship.

3.4 Many types of LULUCF project also lack recognised and approved verification methodologies that can be used to validate the emission reductions/sequestration claimed by a project.

3.5 LULUCF projects also tend to face particular difficulties ensuring that the emission reductions are permanent. For example, if credits are awarded for a change in agricultural practices to improve carbon sequestration (for example zero tillage), the carbon sequestered (and credited through the project) may be released at a later date if there is a change to the tillage regime being practised.

Compliance carbon market

3.6 The foundation of the global carbon market is the Kyoto Protocol, which established legally binding targets for the developed world countries that ratified the protocol. To help meet their targets, countries can use the Kyoto ‘flexible mechanisms’: Clean Development Mechanism (CDM), Joint Implementation (JI) or Emissions Trading. These mechanisms allow for the trading of ‘carbon credits’, or emissions reduction/sequestration units, which can be used for compliance purposes by parties that have legally binding targets (Carbon Trust, 2006).

3.7 In recent years the compliance carbon market has experienced a significant expansion. Growth in 2007 has been estimated at 80%, with a global value of $40 billion (Point Carbon, 2008). The CDM is projected to certify over 2.6 billion tonnes of emissions reductions during the 2008-2012 commitment period (UNFCCC, 2008).

Trading schemes

3.8 The possibility of using trading as a cost-effective way to achieve emissions reduction targets has encouraged nations and groups of nations to develop their own domestic trading mechanisms to help them meet their Kyoto targets. Among these schemes the biggest is the European Union Emissions Trading Scheme (EU ETS), in operation since 1st January 2005. Other schemes are also being developed, for example the New South Wales Abatement Scheme in Australia and the Regional Greenhouse Gas Initiative in the USA. A cap and trade scheme which includes the Agriculture, Forestry and Land Management (AFLM) sector is also being introduced in New Zealand.

3.9 In the UK, Defra have scoped the potential for establishing a market mechanism for the AFLM sector and concluded that a cap-and-trade scheme would not be cost-effective. The bulk of emissions come from farms that, individually, are relatively tiny emitters (even big farms are small compared with installations in the EU Emissions Trading Scheme). If a trading scheme were applied to all farms, the combined administrative and abatement costs would far outweigh the benefits from emissions reductions. If the scheme were applied just to large emitters the potential for reducing emissions would be greatly reduced because only a small percentage of overall emissions would be covered (NERA, 2007).

3.10 However, the review did conclude that a voluntary project-based - or credit-based scheme is a more feasible option and could provide a starting point for any future mandatory scheme.

Assuming 50-75% participation, such a scheme could achieve a saving of 0.2-0.3 $MtCO_2e$ (about 0.5-0.6% of the sector's total) and a net benefit of £0.9m (NERA, 2007).

3.11 Defra, the Environment Agency, Forestry Commission and Natural England have since jointly commissioned an analysis of policy instruments for reducing GHG emissions from the AFLM sector. The aim of the study is to identify the most cost-effective package of policy instruments to reduce GHG emissions from the AFLM sector in England, within an overall UK context, and to provide practical recommendations on how this package of instruments should be implemented. The study will cover the period up to 2022 (to cover the first three carbon budgets) and also consider mitigation potential of policy instruments up to 2050.

Voluntary carbon market

3.12 As well as the internationally regulated compliance market, a parallel but separate voluntary carbon market has emerged. Players in this market engage voluntarily in emissions reduction schemes because they have either set their own reduction targets or wish to reduce or net off their carbon footprint. Strategic reasons why companies buy offsets include addressing climate change, generating goodwill amongst customers and employees, learning by doing, or Corporate Social Responsibility (CSR) interest or obligations. The voluntary market includes the so-called 'retail' carbon market, targeted at companies and individuals that usually have relatively small direct emissions, and wish to reduce their carbon footprint through 'offsetting'.

3.13 The voluntary market has a number of different schemes. However, the emission reduction credits from the voluntary market cannot be traded on the compliance market. In the compliance market most schemes are governed by the Kyoto Protocol, creating emissions reduction units which are transferable. There is no such overarching framework in the voluntary market. This makes the voluntary market not only complex to understand, but also less transparent and extremely diverse in terms of its 'trading units'. For example, some emissions reduction credits traded on this market do not need to pass any additionality criteria, while others do.

3.14 The voluntary market has been working to introduce common standards for projects, based on the compliance market rules. There have been some significant advances in the credibility of a number of carbon offset schemes. The recently launched Voluntary Carbon Standard (VCS, 2007) requires that all projects have an approved methodology and are independently verified. The VCS has also established a global registry to record the credits earned from VCS projects (called Voluntary Carbon Units) to avoid double-counting. However, even with these safeguards in place it is still not possible to sell VCUs on the compliance market.

3.15 While the carbon standards for the voluntary market are often less stringent than for the compliance market, they often have additional co-benefits. They also generally place less of an administrative or financial burden so may be more achievable, particularly for small projects. However, because of the number/lack of standards and the plethora of voluntary schemes operating - some of which are far from robust (particularly forestry schemes) - there is a general lack of confidence in the voluntary carbon market. This is the principal reason that Defra have introduced a Quality Assurance Scheme for Carbon Offsetting. This scheme is aimed at consumers with the first phase restricted to the compliance market.

4 Review of key ecosystems

4.1 Five broad ecosystem types have been reviewed:

1) woodlands
2) peatlands
3) croplands and grasslands
4) coasts
5) marine.

4.2 There has been a widespread literature review of the available evidence. For each ecosystem, the review has been split into the following categories.

Current levels of carbon storage and greenhouse gas fluxes

4.3 An assessment of how much carbon is estimated to be stored in the ecosystem within the UK and any data on levels of greenhouse gas fluxes to and from the ecosystem.

Practices that can reduce CO_2 emissions and /or enhance sequestration

4.4 A review of the understanding of LULUCF and marine management practices which will help to reduce greenhouse gas emissions and/or enhance sequestration rates.

Implications for the natural environment

4.5 It is possible that some practices which are beneficial for CO_2 sequestration may not necessarily have positive impacts on the natural environment. As Natural England has statutory responsibilities for maintaining and conserving the natural environment, it is important that an assessment is made of the implications of widespread uptake of new management practices on the natural environment.

Viability for inclusion in carbon markets

4.6 This review will include a brief assessment of whether projects in each of the key ecosystems are currently viable for inclusion in the carbon market and if not, what barriers would need to be overcome to make them viable.

Key evidence gaps

4.7 The review for each ecosystem will conclude with a summary of the key evidence gaps.

5 Woodlands

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Plate 1 Lowland Beech and Yew Woodland on the Chilterns

Current levels of carbon storage and greenhouse gas fluxes

5.1 The entire UK woodland and forestry estate stores around 150 MtC (Broadmeadow and Matthews, 2003). A net total of 15.11 $MtCO_2$ was sequestered by forestry in 2006 which is equivalent to around 3% of UK CO_2 emissions.

5.2 As noted in Section 2 above, the UK Inventory only accounts for sequestration from woodland planted after 1920 on the assumption that older woodland will have reached equilibrium and no longer actively sequestering carbon. However, this may not necessarily be true for British conditions. Most British woods have been cut-over regularly for centuries so are still likely to be in the carbon accretion stage. For example about a third to half of the woods in England were cut over during the second world war so most of the stems are only about 60 yrs old.

5.3 The amount of CO_2 sequestered from forestry is projected to decrease this decade. This is largely as a result of extensive woodland planting in the 1960s and 1970s coming to commercial felling age. If these stands are restocked or allowed to naturally regenerate, it is anticipated that the sink strength of forests would increase again. The strong dynamics of the strength of the forest carbon sink may in part be an artefact of the modelling system applied, which assumes a single productivity of class/species and thus felling age for broadleaf and conifer species.

5.4 Reported emissions from deforestation are very low and based on unconditional felling licences granted by the Forestry Commission. However, there is some uncertainty in these figures (Levy and Milne 2003), as it does not included unregistered felling and clearance.

5.5 Furthermore, there is a strong biodiversity-led driver to clear large areas of plantation woodland for open habitat restoration purposes. This is technically classified as deforestation in terms of GHG reporting and will, in almost all cases, result in an increase in net greenhouse gas emissions which will need to be recorded in the UK GHG inventory.

5.6 The Forestry Commission is currently developing its policy on open habitats in partnership with a range of stakeholders through an assessment of the change in ecosystem service provision associated with the change from woodland to open habitat. This assessment includes consideration of the implications of open habitat restoration for carbon balance.

Practices that can reduce CO_2 emissions and /or enhance sequestration

Increasing new woodland establishment

5.7 The last century witnessed a marked expansion in UK woodland, from 5 per cent of land cover in 1924 to nearly 12 per cent in 2003. Planting rates, especially of conifers, were at their peak in the 1960s and 1970s, averaging 33,200 ha per year between 1970-79 (Choudrie and others, 2008).

5.8 The scale of new woodland creation has declined in recent years, averaging around 5,000 hectares a year in England since 2002, falling to 3,200 hectares in 2007 (Forestry Commission 2008). An unknown area is planted each year without grant aid and woodland encroachment onto ex-agricultural land may also be significant, but is not recorded.

5.9 The dynamics of tree growth mean that any relatively small increase in the rate of new woodland creation would have limited initial impact on carbon sequestration. As an illustration, increasing current planting rates threefold between 2006 and 2020 would result in additional sequestration of 1.1 $MtCO_2$ by 2020, rising to 1.47 $MtCO_2$ in 2035 (UKCCP 2006). However, these estimates do not include the contribution that the woodland would make, over time, to GHG emissions reduction targets through direct and indirect fossil fuel substitution, which is dealt with elsewhere. This role may develop further as second generation biofuel technology develops.

5.10 In reality, land availability and the challenge to maintain or increase food production means that carbon sequestration through woodland creation can only make a limited contribution to reducing the UK's GHG budget. However, the co-benefits associated with woodland creation makes it an attractive option for GHG abatement in appropriate locations, through also contributing to social, environmental and economic objectives. This approach of carbon sequestration being seen as a secondary rather than primary driver of forestry policy is outlined in 'A strategy for England's Trees, Woods and Forests'. In Scotland, woodland creation can make a larger contribution to GHG emissions reduction (currently sequestering 17% of Scotland's CO_2 emissions) and this is reflected in greater prominence for carbon sequestration as a driver for woodland creation in the Scottish Forestry Strategy and associated Action Plan.

Re-introducing woodland management

5.11 Bringing under-managed and neglected woodland back into management has the potential to enhance its sink strength alongside a range of additional benefits. There is firm evidence that that well managed woodlands from which the timber is utilised generally make a larger contribution to climate change mitigation than unmanaged woodlands. Forestry Commission research has found that existing mixed woodland utilised for bio-energy and product substitution can deliver around four to five times more carbon savings than unmanaged woodland (Broadmeadow, 2006).

5.12 Forestry can provide wood as a renewable fuel source, as identified by the Biomass Taskforce, the UK Biomass Strategy and the Forestry Strategies of England, Scotland and Wales. The UK Climate Change Programme 2006 identifies that the use of arboricultural arisings, harvesting residues and small dimension or poor quality stemwood from ongoing management activity can make a significant contribution.

5.13 More recently, the Forestry Commission has set a target, through its Woodfuel Strategy (FC, 2007), of bringing an additional two million (green) tonnes of woodfuel to the market by the year 2020. This would contribute to reducing emissions, via the substitution of fossil fuels, by 0.4 MtC annually. The figure for annual emissions savings of 0.4MtC is very conservative as it assumes use for co-firing. If used for combined heat and power generation, the figure rises to over 1.2 MtC per annum.

5.14 Only 38% of the annual increment in England is currently being harvested and more than 650,000 hectares of woodland in non-Forestry Commission ownership are not in receipt of management grants (FC, 2007). This does not mean that a proportion of this woodland is not being managed for a range of other objectives, but a sizeable area is likely to be under or unmanaged.

5.15 When compared with other materials, particularly those used in construction, wood products have far lower CO_2 associated with their production. As an example, using treated roundwood for telephone/electricity transmission poles is responsible for 4 tonnes of CO_2 per km, compared with concrete's 17 tonnes and tubular steel's 38 tonnes (Matthews and Robertson, 2005)

5.16 Construction probably represents the sector with the largest potential for product substitution. For example, the CO_2 associated with supplying wooden window frames for a typical house is 150 kg, compared with 500 kg for aluminium frames. A recent study (FC, 2006) has calculated the emissions savings associated with maximising the use of wood in house construction and concluded that savings of up to 73% can be achieved.

5.17 Development of wood technology and an increased usage of wood in the construction industry will maximize these benefits. The Government and the Forestry Commission aim to continue to promote the role of wood as a renewable material in sustainable development though schemes such as 'wood for good', which transfers knowledge of timber systems to the construction industry (UKCCP 2006).

'Continuous cover' forestry

5.18 A range of options is available for woodland management to enhance sequestration such as continuous cover forestry where canopy cover is maintained. Larger carbon stocks are maintained over the long-term and soil disruption at harvest time is minimised to reduce carbon loss. Under this management system, trees generally are grown taller and the bigger ones put on volume faster (Viner and others, 2006).

5.19 While this management system may achieve lower timber volumes than conventional rotational forestry, it does give a steady annual production and avoids fluctuations in the size of the woody biomass and soil carbon caused by clear felling. There are also likely to be benefits to species variety from uneven-aged stands, which encourages biodiversity and resilience to the impacts of climate change (Broadmeadow, 2006). Furthermore, the larger dimension timber that is often produced in continuous cover systems may deliver carbon savings from product substitution.

Implications for the natural environment

5.20 Most forestry activities have the potential to either enhance or damage to the natural environment. Planting on sites that are important for non-woodland habitats and species will result in adverse biodiversity impacts. Inappropriate planting, especially of large-scale monocultures, can in some places, be at odds with distinctive and valued landscape characteristics. Coniferous plantations can also acidify the soil.

5.21 However, new woodland planting that is planned correctly according to the requirements of the UK Forestry Standard can also be of immense value for wildlife and enhance landscape character, especially in areas that have suffered fragmentation and degradation. Woodlands also play an important role for ecological connectivity in the landscape, which in turn will improve the natural environment's resilience to the impacts of climate change.

5.22 New woodland planting is also a key component of green infrastructure and plays an important role in regenerating urban and urban fringe areas. The Community Forests and National Forest are exemplars of this approach and show that new woodlands can deliver a range of environmental, economic and social benefits.

5.23 Different management systems are needed for different sites: continuous cover woodland leads to variety in species composition and uneven-aged stands, which in turn encourages biodiversity and resilience to the impacts of climate change (Broadmeadow, 2006). There will, however, be sites where continuous cover would not be advantageous for biodiversity and/or landscape character, for example, clear fells areas are important in other woodlands for species like the nightjar and woodlark.

5.24 Deforestation of forestry plantations may be desirable in some areas to facilitate habitat and landscape restoration, although the net carbon implications are generally negative. The removal of plantations on blanket and raised bog to meet biodiversity objectives is likely to help to stabilise these large carbon stores in the long-term, although there is some uncertainty in the overall greenhouse gas balance of restoration when methane and nitrous oxide fluxes are accounted for.

Viability for inclusion in carbon markets

5.25 The Kyoto Protocol requires signatory nations to include emissions and sequestration from afforestation, reforestation and deforestation within their greenhouse gas commitment (Article 3.3). There are therefore approved methodologies in place for verifying carbon emissions and sequestration from forestry.

5.26 As such, forestry projects are viable in the Kyoto mechanisms, although in the case of Clean Development Mechanism (CDM) there are caps to limit afforestation and reforestation projects. Forestry is not included in the EU Emissions Trading Scheme (EUETS).

5.27 Forestry projects have been central to the voluntary carbon market from the outset and, until fairly recently, made up the majority of all voluntary projects. However, there have been credibility issues relating to the permanence of sequestration due to fire, pests, disease and land use change. Leakage is also a potential barrier to forestry projects, particularly afforestation on agricultural land which could displace production elsewhere. There have also been concerns that some forestry projects have had adverse biodiversity and social impacts.

5.28 More recently, standards for forestry projects in the voluntary market have improved through schemes like the CDM Gold Standard, which sets out higher environmental and sustainability benchmarks for CDM-approved projects. The Voluntary Carbon Standard (VCS) also includes independently approved methodologies for afforestation and reforestation projects.

5.29 Domestic (UK) forestry offset projects can currently earn carbon credits on some voluntary carbon markets, but there is no mechanism in place to allow an equivalent amount of the UK's assigned amount to be cancelled. This is one reason that domestic forestry offsetting schemes cannot be Kyoto compliant and are therefore excluded from the first phase of Defra's Quality Assurance Scheme for Voluntary Offsetting. Co-funding of many projects through the English Woodland Grant Scheme or Farm Woodland Scheme also raises questions over additionality. Furthermore, as carbon sequestration associated with grant-aided woodland creation is reported under Article 3.3 of the Kyoto Protocol, issues of double-counting test arise.

5.30 The Forestry Commission are working with stakeholders to develop a Code of Good Practice for domestic forestry offsetting schemes that may adopt a tiered approach that reflects both schemes that match up to the requirements of international standards for reporting and verification and those that will make a clear, additional, contribution to reducing the UK's GHG emissions but, for reasons of scale or accounting methodology, cannot comply with the compliance market.

Key evidence gaps

Emissions from deforestation

5.31 An assessment of the extent of emissions from deforestation in the UK is required to be certain that the figure in the Inventory is accurate. This assessment should include the implications for greenhouse gas fluxes of open habitat restoration projects involving deforestation. In part, this will be addressed through the next phase of the National Inventory of Woodland and Trees, although final results are unlikely to be available within the next five years.

Forestry and peatlands

5.32 The greenhouse gas flux implications of forestry operations and forest clearance for open habitat restoration on peat and organic soils needs to be fully understood.

Implications of future climate change on forestry

5.33 Modelling the interactions between climate change, productivity and soil carbon stocks is an important area of research. What will climate change mean for carbon sequestration rates of future forests? To what extent will extreme events and pest and disease outbreaks impact upon carbon stocks?

6 Peatlands

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Plate 2 Blanket Bog near Barbon in Lunesdale, Cumbria

Current levels of carbon storage and greenhouse gas fluxes

6.1 A peatland is a type of ecosystem where carbon accumulates in the peat because plant material deposited from surface vegetation does not decompose completely due to wet conditions. Peatlands are a sink for atmospheric CO_2 because more carbon is sequestered from the atmosphere and fixed in plant biomass through photosynthesis than is released through respiration and loss during decomposition of dead plant material.

6.2 Peatlands have formed because wet conditions slow down the rate of decomposition of dead plant material. In an undamaged state, peat usually remains wet at the surface all year round and will continually accumulate organic matter, sequestering between 0.1-0.5 t/C/ha/year (Dawson & Smith, 2007). Although this is a relatively small amount when compared to sequestration rates from crop harvest yields (IPCC, 2006) carbon sequestered as crops is usually released as CO_2 over a relatively short timescale whereas peat carbon can be accumulated and stored over thousands of years.

6.3 Over the past 10,000 years peatlands have helped to remove significant amounts of CO_2 from the atmosphere and as such have become important global carbon stores. While only covering 3% of the Earth's land area, peatlands are estimated to contain 30% of global soil carbon (around 550 gigatonnes), which is double the carbon stored in global forest biomass and equivalent to around

75% of the total carbon stored in the atmosphere (Parish and others, 2007). European peatlands alone are estimated to store in the region of 41 billion tonnes of carbon, which is equivalent to around seven times annual global anthropogenic carbon emissions (Byrne and others, 2004).

6.4 Peatlands are the single most important carbon store in the UK, with estimates ranging from 4.6 billion tonnes (Bradley and others, 2005) to 5.1 billion tonnes (Dawson & Smith, 2007). The majority of this is in Scotland and Northern Ireland. For England, Bradley and others (2005) calculate that 296 million tonnes of carbon is stored in peat soils. Holden and others (2007) suggest a figure of 475 million tonnes for English and Welsh peatlands.

6.5 As well as acting as a globally important CO_2 sink and carbon store, peatlands are also a source of greenhouse gases. The wet conditions that enable peat accumulation to occur also encourage methane (CH_4) to be formed. Methane has a higher Global Warming Potential than CO_2, which suggests that natural (pristine) peatlands are generally a net source of greenhouse gases, even after accounting for their CO_2 sequestration. However, it is argued by some experts that the different time frame and radiative forcing of continuous CH_4 emissions and CO_2 sequestration should be carefully evaluated, rather than using simple global warming potential calculations (Parish and others, 2007).

6.6 The different approaches to estimating the global warming potential of methane is reflected in the range of estimates of the contribution natural peatlands make to global methane emissions. For example, Byrne and others (2004) note that peatlands are considered to be the largest single natural source of atmospheric methane. However, Parish and others (2007) estimate that natural peatlands contribute between 3-5% of total global methane emissions which, they argue, is part of the natural baseline and due to the rapid turnover time of CH_4, does not contribute to an increase in atmospheric concentrations of methane.

6.7 The general perception that peatlands play a central role in the global climate system is well founded, but they have a more complex and sophisticated function than just being large carbon reservoirs. The fluxes of all three GHGs to and from peatlands are equally, if not more, important to global climate than the amount of carbon they store. Furthermore, there is a wide variability in the characteristics of peatlands, which are located all over the world in temperate, boreal and tropical climates (Parish and others, 2007).

GHG emissions from peatland management practices

6.8 Key peatland management practices in the UK include drainage, burning, grazing, forestry, extraction and agricultural conversion. These management practices will profoundly influence the interacting elements of a peatland ecosystem (water level, pH, nutrient status and plant composition) with consequences on GHG fluxes and subsequently on the carbon store (Bryne and others, 2004).

Drainage

6.9 Drainage is a common land management technique in peatlands. In the UK, it has been estimated that 1.5 million hectares of the country’s 2.9 million hectares has been drained (Worral and others, in print). When peatlands are drained, the aeration of the upper peat layers that are usually anaerobic enhances aerobic decomposition causing increased loss of peat carbon as CO_2, thus depleting the peat carbon store. This loss of CO_2 is exacerbated by seasonal fluctuations in the water table, which increase emissions of CO_2, especially in the summer (Holden and others, 2007).

6.10 Methane production occurs mainly in an anaerobic layer 20-50cm below the water table. A proportion of the methane produced in this layer is oxidized in higher aerobic peat layers. If the water table drops, this zone may be displaced downwards resulting in decreasing methane emissions as the methane is oxidised in the thicker aerobic layers above.

6.11 Drainage generally leads to higher nitrous oxide emissions, if nutrients do not limit N2O production (Maljanen and others, 2004). The rate of nitrous oxide production is driven by nitrification and denitrification processes which have a complex interaction that is often not easy to determine on site (Byrne and others, 2004). Most upland peatlands receive their nutrients only from rainfall (ie are ‘ombtrotrophic’) and so are nitrogen limited, so any excess nitrate produced will be consumed quickly.

6.12 Drainage is also likely to cause an increase in carbon loss to waters. Some studies have shown elevated dissolved organic carbon (DOC) concentrations in drained sites compared to undrained sites (Wallage et al, 2006). Although not a greenhouse gas flux, it is possible that in the order of 40% of the DOC in river waters can be mineralised and released as CO_2 further downstream (Worral and others, in print). DOC should therefore be considered as an integral part of the carbon budget of peatland system and accounted for in any assessment of peatland greenhouse gas fluxes.

6.13 A peatland’s plant composition will also change as a result of drainage. Lowering the water table allows species that favour drier conditions (for example, grasses and woody species including dwarf shrubs) to out-compete peat-forming species such as sphagnum moss, so reducing the ability of peatlands to sequester CO_2 from the atmosphere.

Burning

6.14 In England, it has been estimated that 40% of moorland has received some burn management (Worral and others, in print). Rotational burning is practiced to maintain a mosaic of heather age classes and maximise heather productivity. The evidence for the consequences of prescribed heather and grassland burning is mixed and at times contradictory. Changes to vegetation composition are likely to affect primary productivity, but much depends on the frequency and intensity of burns. Worral and Evans (2008) report that “cool” well-managed burns can keep water tables high meaning that in theory burnt areas could remain net sinks of carbon. Model and field results suggest this is not the case for “hot” burns and wildfires, where damage occurs to the litter layer of the peat and the soil itself and so results in a peatland becoming a net source of carbon (Worral and Evans, 2008).

Grazing

6.15 Grazing on peatlands in the UK is primarily in the uplands and predominantly by sheep. As with managed burning, the number of studies examining the implications of different grazing regimes on the carbon cycle are rare (Worral and others, in print). Light grazing appears to have little effect upon peatland carbon storage, but this is less likely to be the case for intensive grazing (Worral and Evans, 2008). Excessive numbers of grazing animals exacerbate the effects of other damage (wildfires, erosion, pollution) because they reduce the ability of the vegetation to re-colonised bare peat.

Forestry

6.16 Afforestation has been a major cause of net moorland habitat loss over the past century in the UK. An estimated 9% of upland UK peatland has been afforested (Worral and others, in print). Preparation of peatlands for forestry, particularly commercial softwoods, usually requires drainage and often includes deep ploughing to break through water resistant layers that have encouraged peat formation. This drainage has implications for GHG fluxes and carbon storage noted above.

6.17 The subsequent introduction of tree species will generally increase CO_2 fixation rates compared to previous peatland vegetation. However, loss of carbon from the peats which are dried by both the drainage prior to planting and by increased evapo-transpiration through the trees which further lowers the water table is likely to outweigh the benefits from biomass sequestration, particularly if the biomass is removed from the site (Cannel and others, 1993). Losses of carbon on harvesting can also be significant, particularly where stump removal operations are required prior to restocking.

Agricultural conversion

6.18 The use of peatlands for grassland and arable agriculture requires deep drainage and destruction of the original peatland vegetation. Agricultural conversion is usually accompanied by inputs of fertilizer and often lime, which will accelerate decomposition and therefore increase CO_2 emissions. Both grassland and arable use of peatlands result in loss of carbon, but this is especially rapid for arable use due to the enhanced aeration of peat from ploughing (Byrne and others, 2004).

Peat extraction

Plate 3 Commercial peat cuttings

6.19 Preparation for extraction requires drainage followed by the compete removal of the original vegetation. There is therefore an immediate loss of carbon which is largely transformed into CO_2. The greatest loss of carbon, however, occurs because peat that is extracted is largely used for horticulture, which places the peat in an aerobic environment and results in rapid decay into atmospheric CO_2 (Cleary and others, 2005). Peat extracted for fuel is burnt, which also releases all the peat carbon as CO_2.

Emission factors for managed peatlands

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Plate 4 Bleaklow, Dark Peak Derbyshire

6.20 Peatland GHG fluxes tend to have high variability between and within sites and between different management practices, which makes it difficult to produce standard emissions factors that are widely applicable. Peat type (nutrient status), disturbance from management and climate are key parameters for estimating and understanding peatland GHG fluxes (Byrne and others, 2004). Emission factors need to be scientifically robust and ideally based on at least five years of peer-reviewed field data before they can be used to verify emissions benefits for the purpose of carbon trading or offsetting (VCS, 2007). This review has identified three sets of emission factors for managed peatlands that are applicable to English conditions:

- IPCC guidance for national GHG inventories
- CarboEurope project
- UK GHG Inventory.

IPCC guidance

6.21 The IPCC guidance on national inventories includes Tier 1 CO_2 and N2O emissions factors for peatlands managed for extraction (Table 2). Guidance is given for estimating both on-site emissions (ie from drainage and cutting) and off-site emissions (ie from subsequent peat use for horticultural purposes). Methane emissions are be assumed to be insignificant at the Tier 1 level (Blain and others, 2006).

Table 2 On-site emission factors for peatlands managed for extraction in temperate zones (from Blain and others, 2006)

Peatland Type	Emission factors	
	CO_2-C (tC ha^{-1} yr^{-1})	N_20 (kg N_2O-N ha^{-1} yr^{-1})
Nutrient poor (ombrotrophic)	0.2	negligible
Nutrient rich (mineotrophic)	1.1	1.8

6.22 The IPCC guidance requires that the total area of peatlands (both nutrient poor and rich) under drainage is calculated and then multiplied by the above emissions factors. For carbon, this gives a total in terms of Gg C yr^{-1}, which is then multiplied by 44/12 to convert to CO_2. For nitrous oxide, the total is multiplied by 44/28 and 10^{-6} to give a total in terms of Gg N_20 yr^{-1} (Blaine and others, 2006).

CarboEurope project

6.23 As part of the EU-funded CarboEurope project, emission factors for European peatlands have been collated for a range of peatland types under different management conditions (Byrne and others, 2004). These are depicted in Table 3 below.

Table 3 Emission factors based on median figures from measured fluxes from European peatlands in temperate zones (from Byrne and others, 2004)

Peatland Type	CO_2 (t/C/ha^{-1}/yr^{-1})	CH_4 (kg/C/ha^{-1}/yr^{-1})	N_20 (kg/N/ha^{-1}/yr^{-1})	CO_2-C Equivalent (t CO_2-C ha^{-1} yr^{-1}
Bog (ombrotrophic)				
Afforestation	-0.19	11.15	0.04	- 0.11
Drainage	1.10	20	0.04	1.25
Grassland	2.35	2	0.01	2.37
Arable	4.40	0	0	4.40
Extraction (on-site)	1.75	17.25	0.4	1.93
Fen (minerotrophic)				
Afforestation	-0.2	-0.05	1.83	0.04
Drainage	0.4	1.0	1.05	0.55
Grassland	4.12	0.4	5.05	4.79
Arable	4.09	-0.2	11.61	5.63

UK GHG Inventory

6.24 The UK GHG Inventory calculates emissions due to lowland drainage from a model by Bradley (1997) which is driven by activity data from a single source (Choudrie and others, 2008). The baseline (1990) for the area of drained lowland wetland for the UK was taken as 150,000 ha. This represents all of the East Anglian Fen and skirtland and limited areas in the rest of England (see Map 3 in Section 2). This total consists of 24,000 ha of land with thick peat (more than1 m deep) and the rest with thinner peat. Different loss rates were assumed for these two thicknesses as shown in Table 4.

6.25 The large difference between the implied emission factors is due to the observation that peats described as 'thick' lose volume (thickness) more rapidly than peats described as 'thin'. The annual loss for a specific location decreases in proportion to the amount of carbon remaining. Furthermore, as the peat loses carbon it becomes more mineral in structure. The Century model of plant and soil carbon was used to average the carbon losses from these fenland soils over time (Bradley, 1997). The Inventory assumes that a proportion of the carbon lost from drainage will not be atmospheric (ie a CO_2 flux). For this reasons, the actual figure of CO_2 emissions from this category is recorded as 1.15 $MtCO_2$, which is 0.51 $MtCO_2$ lower than the total suggested in Table 4. However, it is not clear in the Inventory methodology how this calculation is made.

Table 4 Area and carbon loss rates of UK fen wetland in 1990 (Choudrie and others, 2008)

	Area (ha)	Organic Carbon Content	Volume Loss Rate $m^3\ m^{-2}\ a^{-1}$	Implied Emissions Factor $tC\ ha^{-1}\ a^{-2}$	Carbon Loss ($tC\ a^{-1}$)	Emissions ($MtCO_2$)
Deep peat	24,000	21%	0.0127	12.8	307,200	1,124,352
Skirtland	126,000	12%	0.0019	1.09	137,340	502,664
Total	**150,000**	**-**	**-**	**2.97**	**445,500**	**1,663,500**

6.26 The UK GHG Inventory does not include any emission factors for ombrotrophic bog, which in England occur mostly in the uplands (with the exception of raised bogs which can also be found in the lowlands). Durham University has a programme of field research underway in the uplands (Peak District and North Pennines), part funded by Natural England, which has been running since 2007. Initial measurements (Worral and others, in print) suggest that under certain conditions, CO_2 emissions from drained bog could exceed both IPCC and CarboEurope emission factors. This is especially the case for severely eroded/gullied and bare peat, for which there do not appear to be any emissions factors.

6.27 Durham University has developed the Durham Carbon Model (Worral and others, in print). This adopts a structured modelling approach, bringing together existing and established models to calculate a complete carbon budget at the grid scale. This is currently being calibrated from on-going measurements in the Peak District. The model considers the following pathways: CO_2 uptake, direct CO_2 and CH_4 release to the atmosphere, DOC, POC and dissolved CO_2. Such a model could be the basis of Tier 3 methodology for estimating emissions from managed peatlands.

Area and condition of English peatlands

6.28 Natural England is co-ordinating the work of the Peat Partnership Project[4] which is determining the location, extent and depth of peat soils in England, using information from the National Soils Map produced by the National Soils Resource Institute (NSRI), British Geological Survey mapping of drift deposits and habitat inventories.

[4] The members of the Peat Partnership Project are Defra, Welsh Assembly Government, Environment Agency, Forestry Commission, Natural England, Countryside Council for Wales and Northern Ireland Environment Agency. The project aims to co-ordinate acitvity in order to use appropriate policy levers and management options for the protection, and restoration of peat soils and habitats

6.29 Peatlands in England comprise areas of deep peaty soils and shallower peaty soils; there are also small scale pockets of deeper peaty material within areas dominated by organic or mineral soil types. The area of these three peatland types is shown in Table 5 and Figure 8.

Table 5 Peatland area in England (from National Soils MAP, British Geological survey and habitat inventory mapping), Peat Partnership Project

Peat Type	Area (ha)
Deep Peaty Soils	679,925
Shallow Peaty Soils	527,193
Peaty Pockets	211,425
Total	**1,418,542**

6.30 Deep peaty soils represent the most concentrated storage of soil carbon in England. They can be categorised into three main types based on the habitats under which they formed (depicted in Figure 9):

- upland blanket bog (including valley mires)
- raised bog
- lowland fen.

6.31 Table 6 summarises the area of each deep peat habitat, the proportion designated as SSSI and the proportion of the SSSI resource classified as in an unfavourable condition. This includes 'wasted' or 'skirtland' fen peat, which was deep peat but has lost the majority of its peat content due to drainage and agricultural management.

Table 6 Area of deep peat habitats in England, proportion designated (SSSI) and SSSI condition (from August 2008 monitoring), Peat Partnership Project

Peatland Type	Area (ha	SSSI ha (% of total peat type area)	Area ha (%) of SSSI not in target condition[5]
Upland Blanket Bog and Valley Mire	347,615	209,193 (60.2%)	45,230 (22%)
Raised Bog	37,856	12,758 (33.7%)	3314 (26%)
Lowland Fen (deep peat)	109,409	17,031 (15.6%)	8389 (49%)
Lowland Fen (skirtland)	185,045	6615 (3.6%)	1118 (17%)
Total	**679,925**	**245,597 (36.1%)**	**58,051 (23.6%)**

[5] Indicates % of SSSI classified as being in "unfavourable no change", "unfavourable declining" or "destroyed or part destroyed" condition

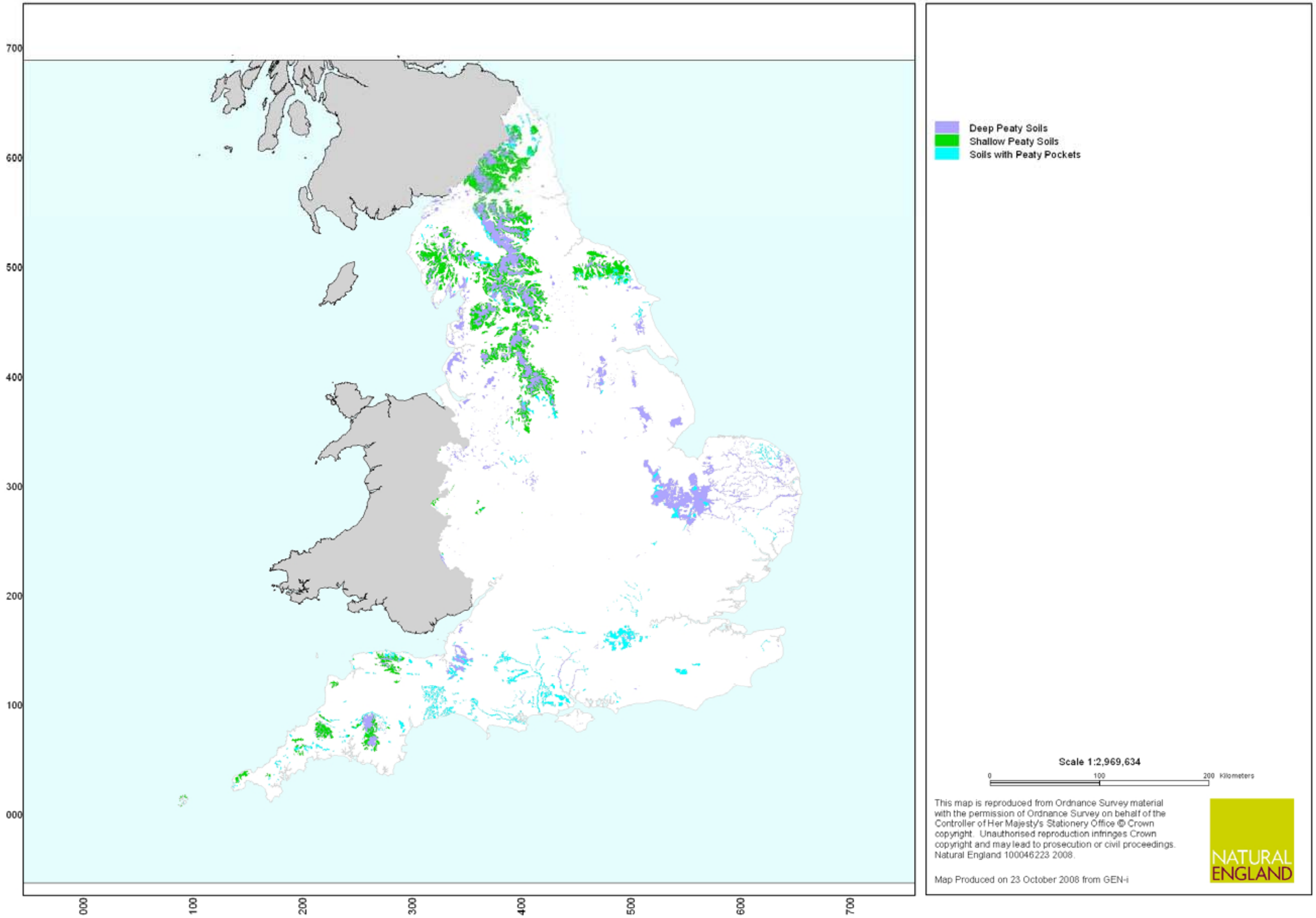

Figure 8 Peatland area in England

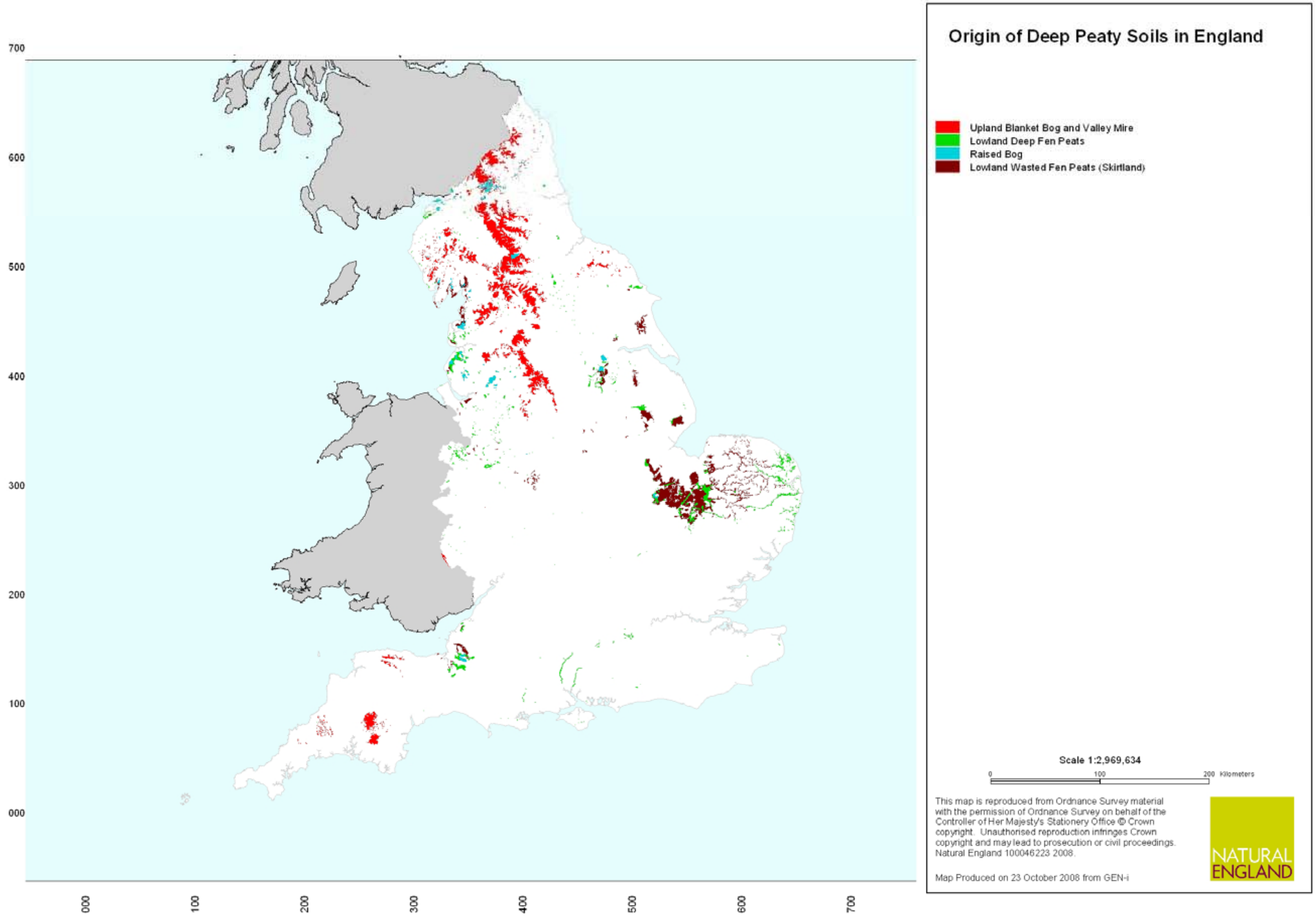

Figure 9 Origin of deep peat soils in England

Blanket bog

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Plate 5 Sphagnum lawn - Blackslade Mire Site of Special Scientific Interest

6.32 Blanket Bog vegetation is dominated by *Sphagnum* mosses and Cotton Grasses with smaller components of dwarf shrubs, sedges and grasses. This sort of vegetation occurs on wet, flat hilltops or gentle slopes and is waterlogged due to high rainfall and poor drainage caused by low slope angle and impermeable drift or geology. These conditions, along with cool temperatures which reduce the rate of organic matter breakdown, result in the formation of deep peat. This peat is typically ~2m deep, but ranges from 0.4 to >8 m, and blankets the landscape, hence the name of the habitat and the term “blanket peat”. Assuming a mean depth of 2m, a mean bulk density of 0.1 g/cm3 and a mean carbon content of 50%, these soils store on average 1000 tonnes of carbon per hectare. Blanket bogs often occur alongside upland nutrient poor fens often called valley mires, and share many similar species. These upland fens also occur independent of blanket bog vegetation.

6.33 Blanket bog is the most widespread type of peatland in England, which along with upland valley mires, makes up 51% of the total deep peat resource. Blanket bog is an upland habitat, mostly located in the Pennine plateaux, with smaller areas in Dartmoor, Exmoor, North York Moors and the Lake District (Holden at al, 2007), as depicted in Figure 9.

6.34 The English uplands contain around 2% of the global resource of blanket bog (Crowle, 2006) and the majority is designated as SSSI for the important biodiversity habitats they support. A significant proportion of the total blanket bog area is also included in national landscape designations (National Park and Area of Outstanding Natural Beauty), which are mainly in the English uplands.

6.35 The overwhelming majority (95%) of the blanket bog resource is uncultivated and is used primarily for sheep grazing and grouse shooting, land uses which may be accompanied by drainage and burning.

6.36 Blanket bog is vulnerable to various form of degradation, including: drainage, overgrazing, wildfire and burning, erosion by wind, water, livestock and human disturbance, atmospheric deposition of pollutants and fertilizer/lime application (Holden and others, 2007).

Raised bog

6.37 Raised bog vegetation is similar in composition to blanket bog, but these habitats occur under specific hydrological conditions. Raised bogs normally begin as fens in topological basins, but when sufficient peat accumulates to completely fill the basin, the surface of the peat is no longer affected by groundwater. If the rainfall is high enough, and the underlying peat, sufficiently poor at conducting water away, the rainfall is sufficient to waterlog the surface, and peat continues to accumulate at the surface. The lack of nutrients from groundwater results in the development of nutrient poor acidic conditions and the vegetation becomes more similar to that in blanket bog.

6.38 Raised bogs are found throughout England, with some extensive areas such as the Solway Mosses in Cumbria, the Somerset and Humberhead Levels and the Manchester /Cheshire mosses (Figure 9). Although more localised than blanket bog and so covering a much smaller land area, raised bogs can still contain significant amounts of peat at depths of up to 10 metres.

6.39 Raised bogs are the main source of peat extraction for horticultural use, which continues today on three of the five largest raised bogs in England (Holden and others, 2007). Another cause of unfavourable condition is agricultural land use.

Lowland fen and skirtland

6.40 Fens are areas where groundwater appears on the surface, but where plants have colonised the water, so that their litter accumulates in wet conditions. Some fens are effectively terrestrialised lakes or ponds, where plants have closed in around the edges and the basin fills up with peat. Other fens are related to flushes and springs, where ground water seeps out, creating a fan of wet ground that is colonised by vegetation, and begins to affect the passage of the groundwater.

6.41 The composition of the vegetation depends on the chemistry of the ground water. In base-rich conditions, fens can be dominated by sedges (notably *Cladium mariscus*), reeds and tall herbs. In base poor or acidic conditions these areas can be dominated by *Sphagnum* and other mosses, sedges, dwarf shrubs and rushes. These habitats are typical of upland valley mires, which been included in the area total for Blanket Bog. The depth of fen peats depends on the depth of the basin, but these have been known to be 6m deep in places. In England , the basins in which fen peat has formed may be metres wide, or tens of kilometres wide.

6.42 The majority of Lowland Fen peat is located in East Anglia. Much of the resource is Grade 1 or Grade 2 agricultural land, which is reflected in the fact that a much smaller proportion is designated SSSI (16%) compared to blanket and raised bog. It is likely that the majority of the non-designated fen resource is under arable cultivation. Cultivation and drainage of lowland fen peats results in decomposition and loss of the peat itself (often called "wastage"), with the result that approximately 185,000 ha of former peatlands in England are now characterised by humose or mineral soils, and contain little true peat. The intensive agricultural management of these areas is reflected in the very low proportion of this land designated as SSSI (3.6%), with much of the wildlife interest being associated with ditches and remnant features of the former wetland.

Uncertainties with CO_2 emissions from peatlands in the UK GHG Inventory

6.43 As noted in Section 2 and Table 4 above, the UK GHG Inventory records CO_2 emissions from lowland peat drainage at 1.15 $MtCO_2$ (2006). This figure is reached by applying an implied emissions factor to 150,000 ha of drained peatlands, of which 145,000 ha is located in the East Anglian fens and a further 5,000 ha in the north-west and Somerset Levels (Figure 3). Of this total, the Inventory classifies 24,000 ha as ‘deep peat’ (>1 metre depth) and the rest as ‘thin’ peat.

6.44 Analysis by Natural England indicates that the total area of deep peat soils is significantly higher than that recorded in the Inventory, being just under 680,000 ha for England alone (Figure 9). The estimated area of lowland fen peat in the Inventory is nearly half the area calculated by Natural England (294,454 ha). This figure does not even include raised bog (37,856 ha), most of which is located in the lowlands. Application of the Inventory emissions factors to the area of lowland fen estimated by Natural England suggests that CO_2 emissions from lowland drainage alone is significantly higher (by a factor of five) than that recorded in the Inventory (Table 7).

Table 7 Estimated CO_2 emissions from lowland fen drainage using Natural England's estimate of lowland fen area and UK GHG Inventory Emissions Factors

Peat Type	Area (ha)	Implied Emissions Factor[6] (tC ha^{-1} a^{-1})	Carbon Loss (tC a^{-1})	Emissions (tCO_2)
Deep Fen	109,409	12.8	1,400,435	5,125,592
Skirtland Fen	185,045	1.09	201,699	738,218
Total	**294,454**		**1,602,134**	**5,863,810**

6.45 The figure in Table 7 may be an over-estimate as not all of the 295,000 ha of fen peat is likely to be losing carbon at the rate implied by the Inventory. A more accurate figure would need to account for the proportion of carbon loss that is not emitted as CO_2, although as noted above it is not clear how the Inventory calculates this. Also, a proportion of this land will not be cultivated and some will represent semi-natural habitat as around 16% of lowland deep fen peat is designated as SSSI. However, as noted in Table 6, a high proportion (49%) of the SSSI resource is not in target condition, and even uncultivated drained peatland emits CO_2 at accelerated rates. Even assuming no emissions from SSSI or uncultivated land, and only 56% of land under cultivation (as indicated from IACS 2004 land use figures for deep fen peats), this would still result in a total emissions figure of 2.8 $MtCO_2$. Considering these caveats, it is reasonable to assume that the true emissions of CO_2 from drained lowland peatlands is likely to be between 2.8 and 5.8 $MtCO_2$ a^{-1}.

6.46 There is also a strong likelihood that the Inventory is under-estimating CO_2 emissions from peat extraction, which it records as 0.42 $MtCO_2$ (2006). The calculation used does not appear to account for emissions associated with the drainage necessary prior to and during cutting and extraction, despite there being IPCC Emission Factors available for this assessment.

6.47 It is evident that the Inventory is significantly under-estimating the area of peatlands and therefore is almost certainly under-recording CO_2 emissions from drained and degraded peat, as well as probably under-estimating emissions from peat extraction. The Inventory does not include emissions from upland blanket bog at all, even though this habitat makes up just over half (51%) of England's total deep peat resource. The Inventory is also clearly under-estimating emissions from lowland peat. The scale of this under-estimation is potentially significant, as CO_2 emissions from drained peatlands are likely to be between **2.8 and 5.8 million tonnes** a year. If this is the case, then the LULUCF sector may be currently acting a net source of emissions, even after accounting for sequestration from forestry, instead of being a small net sink.

6.48 To put this figure in context, Table 8 shows CO_2 emissions from a range of sources on a similar scale, which all arguably have a higher public and policy profile than peatland emissions.

[6] From UK GHG Inventory

Table 8 CO_2 emissions in 2005 from selected sources (from Choudrie and others. 2008)

Source	CO_2 Emissions ($MtCO_2$)	Proportion of total UK CO_2 emissions (%)
Railways	2.03	0.35
Civil Aviation[7]	2.47	0.43
Metal Production[8]	2.47	0.43
Chemical Industry	3.25	0.56
Agricultural Energy Use	4.46	0.77
Cement Production	5.42	0.94

6.49 Further work is required to better quantify CO_2 emissions from both upland and lowland peatlands. Natural England is currently undertaking an assessment of the condition of England's deep peat resource (for both designated and non-designated areas) as part of the Peat Partnership Project. This will include an assessment of likely CO_2 emissions from degraded peatlands, using recognised emission factors. We aim to publish this assessment in summer 2009 and will work closely with Defra and CEH to improve the accuracy of the UK GHG Inventory.

[7] Defined as flights that take-off and land within the UK

[8] Includes iron, steel and aluminium production

Practices that can reduce CO_2 emissions and /or enhance sequestration

Restoration of degraded peatlands

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Plate 6 Common Cottongrass growing on re-wetted abandoned peat cuttings on Thorne Moors, part of Humberhead Peatlands NNR

6.50 Degraded peatlands can generally be restored back to functioning wetland ecosystems by raising the water table to pre-drainage levels, described as 're-wetting' (IPCC, 2006). The objectives of restoration tend to be for improving biodiversity and wildlife habitat, reducing flood damage, improving water quality and recharging aquifers (Byrne and others, 2004. Holden and others, 2007).

6.51 Restoration can include a range of activities, such as blocking drainage channels (known as "grips" in the English uplands), reducing stocking densities and frequency of burns, limiting wildfire incidents and the re-vegetation (through seeding) of bare peat. In the lowlands, raising water levels in ditches/dykes and ceasing cultivation can also restore degraded fen and raised bog.

6.52 The carbon benefit of peatland restoration can be considered to be a threefold 'triple win' if it results in:

1) avoided loss
2) transitionary sink
3) perpetual sink.

6.53 Firstly, the peatland could be a net source of CO_2 and so if the site is restored to a net sink then the carbon loss is avoided. Secondly, between the state of a damaged peatland, which is a net source, and a pristine peatland, that can continuously accumulate carbon, there is a transitionary stage. This stage can be of carbon benefit due to both avoided losses and net gains of carbon, for example new peat soil filling in blocked drains. Thirdly, many studies have demonstrated that well-managed or pristine peatlands provide perpetual sinks of CO_2 (Worral and others, in print).

6.54 Rewetting represents a shift away from aerobic decomposition under drained conditions towards a far greater proportion of anaerobic decomposition as the water table nears the soil surface. The resulting processes of denitrification (occurring when the water table is fluctuating) and methanogenesis (occurring under strictly anaerobic conditions) lead to the formation of both N2O and CH_4 respectively (Gauci, 2008).

Emission factors from restored peatlands

6.55 There are no IPCC Tier 1 emission factors from restored peatlands and a key uncertainty is the scale of methane emissions post-restoration. The IPCC note that this is an area in need of “methodological development”, but do give a range of from 0 to 60 kg CH_4 ha^{-1} yr^{-1} for peatland soils with forest cover in temperate climates (IPCC, 2006).

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Plate 7 Geojute stabilising bare peat for moorland restoration project

6.56 The EU funded CarbonEurope project proposes emission factors for restored bog and fen, taken from median values from a range of European sites. These are depicted in Table 9.

Table 9 Emission factors based on median figures from measured fluxes from restored European peatlands in temperate zones (from Byrne and others, 2004)

Peatland Type	CO_2 (tC ha^{-1} yr^{-1})	CH_4 (Kg C ha^{-1} yr^{-1})	N_20 (Kg N ha^{-1} yr^{-1})	CO_2-C Equivalents (t C ha^{-1} yr^{-1})
Ombrotrophic bog	0.62	15	0.02	0.736
Minerotrophic fen	No data	12.4	0.64	0.179*

* Without CO_2-C

6.57 For the purposes of generating potential carbon revenues from peatland restoration projects in the absence of recognised emission factors, estimates of methane emissions should be based on adopting figures from the top-end of the range of studies. In the case of the CarboEurope data this is 71 kg CH_4-C ha^{-1} yr^{-1} from restored bog and 18 kg CH_4-C ha^{-1} yr^{-1} from restored fen (Byrne and others, 2004).

6.58 A key research question is to ascertain if these 'extreme' figures are representative of post-restoration methane emissions in English peat bogs and fen. An initial review of studies in the literature for comparable restored peat situations, indicates that this level of CH_4 emissions is not unreasonable for ombrotrophic bog (Natural England, in press).

6.59 There is some evidence of a possible suppression of methane emissions from fen peatlands with increasing sulfate (SO_4) deposition (Gauci and others, 2004). Research in the Great Fen restoration project in eastern England suggests that the fen habitat had a 40% reduction in CH_4 emission, reflecting the high SO_4 content of the Great Fen soils. This may also be an underestimate given that wetland ecosystems exposed to very high inputs of SO_4 can have CH_4 emission reduced by up to 70% (Gauci, 2008). However, not all lowland fen peatlands will have high SO_4 levels.

6.60 It is also important to improve understanding of timescales of post-restoration GHG fluxes. For example, a review conducted by Dawson and Smith (2007) reports an enhanced CO_2 sink for the first 20 years following rewetting. In the second phase emissions of CH_4 are reduced and the CO_2 sink term is largest and in the third phase, both N2O and CH_4 emissions are reduced.

6.61 The Durham Carbon Model (noted above) is able to predict the implications of different management changes and/or restoration on the carbon budget at the grid scale. With further calibration and improvements, based on continued field measurements, this model could provide a robust and verifiable approach to calculating post-restoration GHG fluxes.

Potential GHG benefits from peatland restoration

6.62 Despite the lack of recognised pre-and post-restoration emission factors and the uncertainty regarding methane emissions, there is evidence that peatland restoration will, in general terms, deliver GHG benefits.

6.63 The CarboEurope study shows clearly that a restored peatland will emit less GHGs than a peatland undergoing drainage, extraction or agricultural use. The GHG savings from bog restoration can be significant, as depicted in Table 10.

Table 10 GHG reductions from ombrotrophic bog restoration from selected management types in Global Warming Potential (CO_2-C Equivalents Kg ha^{-1} yr^{-1}). Data interpreted from Byrne and others, 2004

	Drained		Grassland		Arable	
	GWP reduction	%	GWP reduction	%	GWP reduction	%
Bog	517	41	1631	68	3664	83

6.64 The primary GHG benefit from peatland restoration is the **avoided loss** of emissions. Sequestration of CO_2 following restoration will also deliver benefits, but at a lower rate per hectare. There is also a lack of evidence on the extent to which active sequestration re-starts following restoration, particularly for fenlands (Bryne and others, 2004).

Cost-effectiveness of peatland restoration

6.65 The costs of peatland restoration vary depending on the type and scale of degradation. The restoration of bare, eroded and gullied peat can be expensive particularly if the site is remote and inaccessible. Restoration of raised bog can also be costly, as it will often involve re-profiling and landscaping. Figures of £2,000/ha and above are often cited. Grip-blocking tends to be less expensive, depending on the density of grips. The Peatscapes project in the North Pennines AONB has estimated that average costs are £1 per metre for grip-blocking.

6.66 Defra commissioned a UK Peat Compendium in 2007 which reviewed existing restoration projects. It found that the median project cost was £1600/ha, although for many projects this included the cost of land purchase (Defra, 2008).

6.67 There are also other costs to consider, such as opportunity costs for the landowner. This would particularly be the case if restoration results in a loss of revenue due to the previous land use becoming untenable. There may also be long-term maintenance costs. Further analysis is required to provide more accurate estimates of cost-effectiveness of peat restoration at the UK scale.

6.68 It would also be necessary to take account of the implications of widespread peatland restoration requiring productive agricultural land to come out of production. It would be necessary to compensate for lost revenue to make restoration economically viable to the land owner, but there is also the risk that restoration could result in production being transferred to non-managed peatlands (the leakage issue).

6.69 Leakage could still be an issue even if production were transferred to a mineral soil, as this may require increased inputs (for example of inorganic fertiliser) and/or the cultivation of permanent grassland sites which would result in increased loss of soil carbon. These emissions would need to be accounted for when calculating the overall GHG reduction from peatland restoration. Leakage is unlikely to be a significant issue for the restoration of blanket bog, as the vast majority of the resource is not used for intensive agricultural production and many pre-restoration activities could potentially continue post-restoration. The issue of leakage is potentially more important in the lowlands, as much of the deep fen, skirtland and raised bog peatland resource is Grade 1 and 2 agricultural land.

Implications for the natural environment

6.70 The restoration of peatland habitats will almost always result in significant biodiversity gains and help to restore damaged wetland habitats. However, there may be adverse water quality implications of wetting up formerly intensively used arable land if there is any possibility of pesticides and/or fertilisers being washed out.

6.71 Peatlands are often rich in archaeological remains and, while these are often threatened by peat degradation, restoration can also impact adversely on these features. It is therefore important that the site and all proposed operations are assessed by a qualified archaeological specialist before works begin.

Viability for inclusion in carbon markets

6.72 There are currently no internationally recognised methodologies for verifying the potential GHG savings from peat restoration projects. Furthermore, non-forestry land-based projects such as peat restoration are currently not allowed within the CDM or EU-ETS. In the absence of a verification methodology, peat restoration projects are currently unable to engage with the voluntary carbon market.

6.73 A verification methodology will need to set out how a project assesses and verifies baseline GHG emissions from a degraded peatland and then how to predict/demonstrate GHG emissions post-restoration using recognised emission factors. The GHG reductions (per ha/year) will be the difference between the two measurements. It may also attempt to quantify accumulation rates to account for any post-restoration sequestration. However, this will require a judgement on whether the carbon benefits from including sequestration outweigh the additional verification costs.

6.74 It needs to be determined whether domestic (UK) peat restoration projects would meet the additionality test. An assessment would need to be taken at a national scale to determine if there are barriers (in terms of investment, technology or institutional) which carbon revenues could overcome. This assessment would also need to determine if peat restoration is already in common practice in the absence of carbon revenue and if so, what existing financial incentives exist to deliver restoration. It is likely that the vast majority of current restoration is funded through direct public subsidy, which suggests that there is no market-driver or incentive. This could mean that there is a general case for additionality being met, on the basis that there are clear investment and market barriers which carbon revenues could overcome.

6.75 It is also potentially possible for restoration projects to be funded by a mixture of carbon and non-carbon revenues, as long as it can be demonstrated that the carbon funding ‘tipped the balance’ to enable the project to be delivered on an appropriate scale.

6.76 As with all land-based projects, permanency would be a potential barrier to peat restoration projects. However, mechanisms can be established to overcome this issue, such as insurance schemes where a proportion of the credits earned are banked to cover against unexpected loss. Carbon credits could also only be claimed for avoided loss for the period it would have taken for all the peat to be lost under a "business as usual" situation. For example, if a degraded peatland is losing 2 cm of peat a year and has only 1 m of peat remaining, credits for restoration could only be claimed for 50 years, which is the amount of time it would have taken for the peatland in question to have been completely lost without restoration.

6.77 Domestic peat restoration projects would currently not count as double-counting as the UK did not sign up to all measures in Article 3.4 of Kyoto, so any GHG emission reductions delivered could not be formally counted towards the UK’s Kyoto target. However, to avoid the double-counting issue in the future, there is a need for the UK to put in place a mechanism that will account for emission reductions delivered by domestic offset projects and ‘cancel’ the equivalent Assured Assigned Units (AAU) from the UK’s international commitment.

6.78 Alternatively, the UK could allow the use of the Kyoto mechanism Joint Implementation, which could potentially include peat restoration projects subject to the additionality, verification and permanence tests being met. This would also require the UK’s GHG Inventory to be accurately recording GHG emissions from peatlands, so that any subsequent savings from restoration projects are reflected in the inventory and the credits generated converted from the UK's AAUs to Emission Reduction Units (ERUs).[9]

Key evidence gaps

National geographical analysis to identify and map the exact location of England's peat resource, quantify its current condition status and likely CO_2 emissions, and estimate the costs of restoration

6.79 More work is required to produce an accurate map of England's peat resource, including improved estimates of peat depth and volume. This analysis also demands the production of more accurate data on the state and condition of England's peatlands. We need to know the proportions of peatlands which are drained, gullied, eroded, grazed, being actively extracted, under forestry operations and cultivated. This will allow for more precise estimates of current GHG emissions and give an accurate estimate of the economic costs of restoration.

6.80 One of the objectives of the joint Peat Partnership project is to undertake this mapping exercise. Natural England is leading on this work and expects to report in summer 2009.

Development of robust, peer-reviewed Emission Factors for a range of managed and restored peatlands in England

6.81 The Emission Factors used by the UK GHG Inventory are not necessarily the most appropriate for the peatland resource in England. There is significant variability across locations, depending on a range of often localised factors such as topography, local climatic conditions, soil and vegetation type, land use and management practices. More field measurement of GHG fluxes at a range of upland and lowland catchments is necessary to improve the accuracy of the baseline GHG emissions from England's peatland resource. Currently, minimal data on these fluxes is available due to limited research in this area..

6.82 Similarly, there is a need to improve our understanding of post-restoration GHG fluxes, particularly of methane. It is necessary to have field measurements from a range of sites to give a more accurate assessment of GHG fluxes and their uncertainty under the wide range of natural and managed conditions.

Assessment of the impact of climate change on GHG fluxes and carbon storage for England's peatlands

6.83 The scale of projected climate impacts over the course of this century (and beyond) could have significant implications for peatland dynamics and therefore on their GHG fluxes and carbon storage.

6.84 It is possible that climate change could directly increase carbon loss and other GHG emissions from peatlands through the increase in biological activity due to warming and also due to changes to the seasonal distribution of rainfall. Losses of carbon to drainage water may also be affected, which would impact on net carbon budget and potential loss of CO_2 from rivers. It is not inconceivable that widespread peatland restoration may be necessary just to hold CO_2 emissions at current levels, let alone reduce them below the baseline.

6.85 The forthcoming UKCIP scenarios, which are due to be launched in spring 2009, could provide an important and useful tool for improving our understanding of the implications of climate change for the future management of UK peatlands.

[9] ERUs are the credits generated by Joint Implementation projects. 1 ERU = 1 tonne of CO_2e

7 Croplands and Grasslands

Current levels of carbon storage and greenhouse gas fluxes

7.1 An estimated 77% of the UK's land area is used for agricultural production, in the form of arable (tilled) croplands and managed grasslands (Defra and others, 2007).

7.2 The majority of grassland and arable soils are mineral-based and so have less carbon content than peat soils, but cover a much larger area. Grasslands store more carbon than any other land use in England (686 million tonnes), with arable land being the second largest store (583 million tonnes) (Bradley and others, 2005).

7.3 As noted in Section 2, CO_2 emissions and sequestration from croplands and grasslands land use categories are recorded as part of the LULUCF section of the UK GHG Inventory. In general, cropland management practices and land use change to croplands from forestland and grasslands result in emissions. There are also some emissions from grassland management practices (such as biomass burning and liming), but conversion of land to grasslands sequesters CO_2. Overall, grassland and cropland management was a net source of 6.68 $MtCO_2$ in 2005, as shown in Tables 11a and 11b below.

Table 11a CO_2 emissions from cropland and grassland land use categories in UK GHG Inventory, 2006

Land Use Category	CO_2 Emissions ($MtCO_2$)
Land use change to croplands from grasslands and forestland	14.29
Biomass burning on grasslands	0.13
Liming on croplands	0.11
Liming on grasslands	0.08
Total	**14.61**

Table 11b CO_2 sequestration from cropland and grassland land use categories in UK GHG Inventory, 2006

Land Use Category	CO_2 Sequestration ($MtCO_2$)
Land use change to grasslands from croplands and settlements	7.93

Practices that can reduce CO_2 emissions and /or enhance sequestration

7.4 There are two main forms of land management that can manipulate the amount of carbon retained in agricultural soils and vegetation: land-use changes and changes to agricultural management practices.

Land use changes

7.5 Changing land use can often significantly alter the amount of carbon retained in agricultural soils and vegetation. If the change involves taking land out of agricultural production, then there is likely to be an increase in the amount of carbon stored in the soil and vegetation until a new, higher equilibrium is reached.

7.6 Practices which result in land being taken out of agricultural production could create a higher demand for imports, resulting in greater transportation distances and fuel consumption, effectively ‘leaking’ greenhouse gas emissions elsewhere. This issue is of less relevance in relation to land of marginal productivity or where production is in decline anyway for other socio-economic reasons. Conversely, land use changes which intensify agricultural production will often result in soils rapidly losing carbon. Some of the key land use changes that can increase retention of carbon are discussed below. New woodland establishment is discussed in Section 3 on Woodlands.

Expanding field margins

© Natural England

Plate 8 6m autumn-sown grass margin growing in heavy clay soil, buffering an existing hedge and woodland

7.7 Falloon and others (2004) estimates that up to 1.5 MtC could be stored in soils in grassed field margins on croplands and/or intensively managed grasslands, with additional benefits from reduced nitrous oxide emissions. A more recent review of the contribution to mitigation from the Environmental Stewardship scheme (Defra, 2007b) found that six metre buffer strips on both croplands and grasslands are the most effective options for mitigation. Mean Soil Organic Carbon (SOC) content can be increased from 256 $tCO_2e\ ha^{-1}$ for croplands and 293 $tCO_2e\ ha^{-1}$ for grasslands to 440 $tCO_2e\ ha^{-1}$ (Defra, 2007b).

Energy crops

7.8 There are two main forms of bio-energy: perennial biomass crops for heat and power (such as short-rotation coppice and *Miscanthus*) and feedstocks for liquid biofuels (typically Oil Seed Rape for bio-diesel and wheat for bio-ethanol).

7.9 It has been estimated that the conversion of 10% of UK agricultural land to perennial energy crops could reduce the UK's greenhouse gas emissions by around 3 MtC per year. This carbon benefit would come from a combination of increasing levels of soil organic carbon and sequestration by vegetation and from reductions in the use of fossil fuels (Smith and others, 2000b; ADAS 2003). However, this figure does not account for any losses of soil organic carbon from harvesting, especially of *Miscanthus*.

Habitat creation

7.10 Changing land use from an intensively managed system (either as arable or intensive grasslands) to a semi-natural habitat can significantly increase soil carbon levels.

7.11 Defra (2007b) found that habitat creation options on arable and/or intensive grasslands produces some of the highest carbon benefits. This research has concluded that the scheme currently reduces UK emissions by 3.77 $MtCO_2$ a year (Defra, 2007b).

7.12 Habitat maintenance options do not have a similar impact to habitat creation and restoration, as carbon storage is likely to be close to maximum. However, the maintenance of semi-natural habitats is important from a carbon perspective, as reversion to a more intensive system will result in the loss of carbon to the atmosphere and the establishment of a new lower soil carbon content (Defra, 2007b).

Pond creation

7.13 Ponds can capture carbon through uptake by algae and plants and subsequent deposition when the plants die. Carbon can also be accumulated in sediment from run-off (Pond Conservation, 2008).

7.14 Research from the USA suggests that constructed farm ponds accumulate sediment, and therefore carbon, up to 500 times faster than lakes in more natural environments (Downing and others, 2007). The volume of sediment deposited varied as a function of lake and watershed size, but smaller ponds had greater deposition and accumulation rates per unit area.

7.15 Extrapolation suggests that the large number of small waterbodies globally (more than 250 million) may bury four times as much carbon as the world's oceans (Downing and others, 2007).

Agricultural management changes

7.16 In temperate climates the amount of carbon stored in arable soils is in part dependent on management practices, which may either enhance inputs of carbon (for example from adding crop remains, manure and compost) or exacerbate losses (for example from frequent cultivation and drainage); (Smith and others, 2007).

7.17 Some of the key practices that can, at least theoretically, enhance inputs of carbon are discussed below. Importantly, these changes would not necessarily result in any significant reduction in agricultural production and so the issue of emissions leakage is less relevant.

Conversion to reduced or no tillage systems

7.18 Reduced tillage involves shallow cultivation using discs or tines to an average depth of 10-15cms. Approximately 43% (2.4 million hectares) of arable land in England is currently cultivated by reduced tillage systems (Defra. 2007a). Zero tillage involves no cultivation at all, instead using direct drilling or broadcasting techniques and is currently used on around 7% (0.4 million hectares) of England's agricultural land (Defra. 2007a).

7.19 Both systems are widely practised in the Americas and Australia, mainly for water conservation purposes. In the UK, most land under reduced or zero tillage is deep ploughed usually once every rotation (Defra, 2007a). There have been a limited number of studies of the implications of reduced and zero tillage for soil organic carbon levels in the UK, though Smith and others, (2000a) estimated potential savings of about 1 MtC per year.

7.20 These studies indicate that the average soil carbon increase is 0.31 tC/ha/yr for zero tillage and 0.16 tC/ha/yr for reduced tillage (Defra, 2007a), with slightly higher rates estimated by Smith and others (1998, 2000b). Both systems also deliver further carbon reductions from less intensive energy consumption in the form of fewer cultivation passes and a decrease in nitrate leaching resulting in slightly lower nitrous oxide emissions, though studies elsewhere have shown increased nitrous oxide emissions (MacKenzie and others, 1998). Several recent papers suggest that the apparent carbon sequestration benefits of reduced tillage might in fact simply be measurement artefacts. (Baker, J. M. and others, 2007). There are also other benefits, such as a reduction in soil wind/water erosion rates, increased soil water retention and reduced production and fossil fuel costs (Defra, 2007a).

7.21 There are some uncertainties about the consequence of reverting from conventional to zero/reduced tillage for emissions of nitrous oxide due to increased water-logging resulting in anaerobic conditions. Some studies indicate that in English conditions this would almost offset all of the benefit of increased carbon storage (Defra, 2007a). However, there are very few studies and this is a clear evidence gap.

7.22 A key concern with this measure is reversibility (Smith, 2005). If land is conventionally ploughed a few years after it has been under zero/reduced tillage, then it will lose carbon more rapidly than it has accumulated it. Although this would negate any carbon retention delivered for a localised land area, the wider effect of expanding reduced and minimum tillage may still provide an overall net increase in soil carbon.

7.23 If both cultivation systems were to be expanded into the 2.8 million hectares of conventionally ploughed agricultural land in England then there could be the potential to deliver significant GHG reductions, although there are clearly a number of evidence gaps that need to be addressed to better understand the potential GHG benefits.

Increasing organic matter returns

7.24 Applying organic returns (which include farmyard manure, crop and/or straw residues, bio-solids such as sewage sludge, green waste compost and paper crumble) can retain and increase soil organic carbon, as well as provide other benefits to soil through increasing plant nutrients and improving water retention, aeration and stability (Defra, 2007a). Just over 5 million hectares (35%) of UK agricultural land currently receives organic returns, the majority of which is on grassland (Defra, 2007a).

7.25 There have been a wide range of studies, some of them long-term, that provides a good evidence base on whether recycling organic materials increases soil carbon and by how much. Some organic returns[10] can deliver reductions in nitrous oxide emissions, through a resulting decrease in inorganic fertiliser input and in turn less carbon dioxide emissions from fertiliser production.

[10] With the exception of paper crumble which immobilises N in the soil, thus requiring additional application of inorganic fertiliser to compensate (Defra, 2007a)

7.26 Potential additional soil carbon storage ranges from 0.3-1.6 (t/C/ha/yr) with a typical annual application. Equivalent estimates for the technical potential of these measures in UK by Smith and others (2000a) were <1 Mt and ~1.7 Mt for straw addition and surplus manure addition, respectively.

7.27 However, recent research (Defra, 2007a) suggests that there is not significant scope to expand organic returns much beyond current levels, especially for farmyard manure. The potential for increasing green waste compost appears to be more significant, although there may be emissions from transportation that would need to be accounted for.

Extensification

7.28 This broadly includes a range of management options such as extending crop rotations, including more intercrops and grasses, use of deeper-rooted crops and, for grasslands, changing to clover-based pastures to reduce nitrogen applications.

7.29 The expansion of legumes to replace inorganic fertilisers can potentially deliver significant increases in soil carbon if such conversion occurs at a large scale, although there will remain a requirement for other agricultural inputs. There will also be associated reductions in emissions of nitrous oxide and carbon dioxide from the resulting fall in the application and manufacture of inorganic fertilisers.

Conversion to organic farming

7.30 Conversion of arable production and especially dairy management to organic has been shown, in some studies, to enhance soil carbon levels and reduce greenhouse gas emissions. Research by ADAS (2003) found that dairy conversion has the most significant potential for greenhouse gas reductions.

7.31 However, other studies have shown that organic production can increase greenhouse gas emissions. For example, a Defra-funded Cranfield University project (project IS0205) reported that organic production of beef, poultry, eggs and milk, on a product basis, shows an increase in emissions. Further, across all 10 commodities investigated in IS0205, organic production always required more land to produce the same amount of produce (65 to 200% more). More research is required to understand the implications of organic systems for soil carbon.

Implications for the natural environment

7.32 Many of the agricultural management changes that enhance soil carbon are consistent with more sustainable, less intensive, mixed farming systems. Some of the changes are already being implemented through conversion to organic agriculture or agri-environment schemes in order to deliver biodiversity and landscape benefits, such as expanding field margins (Smith, 2006).

7.33 Energy crop production could have significant impacts, both positive and negative, on landscapes, biodiversity, soils and water resources. These impacts will generally be determined by the overall scale of production, the specific sites chosen, the cultivation methods adopted, the crops grown and the agricultural practices they have replaced.

7.34 Overall perennial energy crops (specifically SRC and to a lesser extent *Miscanthus*) have been shown to potentially benefit biodiversity, particularly bird species typical of scrub and generalists, depending on the scale of planting. Correspondingly, there may be negative impacts on the range and abundance of farmland specialist species associated with those crops that are replaced by bio-energy. The landscape impacts of perennial energy crops could be significant, but will vary according to scale, location, existing land cover, landform, landscape character, landscape sensitivity and landscape value.

7.35 Some agricultural carbon management practices could have adverse impacts on water and air quality, particularly the risk of increasing diffuse pollution from organic returns.

Viability for inclusion in carbon markets

7.36 A number of cropland and grassland management practices can help to retain and increase carbon stocks in agricultural soils. There is in general a sound evidence base in place, with some good knowledge of what different practices will mean for retaining carbon, although there are still a number of gaps on their relative effectiveness especially in a UK context.

7.37 Improved agricultural soil management practices are not eligible in the international compliance carbon market (CDM and JI). The IPCC have developed methodologies for accounting for emissions and sequestration from cropland and grassland management, which all UNFCCC countries have to include in their annual GHG Inventories. However, as outlined in Section 2, inclusion of these measures currently optional under Article 3.4 of Kyoto and they have not been included in the UK's commitment.

7.38 A number of voluntary schemes allow for the inclusion of soil management offset projects and have developed methodologies for verifying their carbon savings. Two international examples are the Chicago Climate Exchange (CCX) and the Voluntary Carbon Standard (VCS).

7.39 The CCX is a voluntary system (based mainly in Canada, the US and Mexico, but with an expanding European outlet) which sets self-imposed, legally binding reduction targets on its members. Participant members have an emissions cap based on historic (1999-2002) emission levels. To comply, members can either reduce their emissions below their cap or purchase offset credits generated from projects in the US, Brazil, Canada or Mexico that include carbon sequestration through conservation tillage in agricultural soils and rangeland restoration (Carbon Trust, 2005).

7.40 The VCS includes guidance for Agricultural, Forestry and Other Land Use Projects (VCS 2007). One of the categories within the AFOLU guidance is for Agricultural Land Management projects which include practices such as improved cropland management (for example no-till, use of cover crops, creation of buffer strips, etc), improved grassland management (for example increasing forage productivity, introducing species with longer root systems and decreasing degradation from over-grazing) and cropland and grassland land use conversions (for example cropland to grassland, reduction in drainage of organic soils, etc). In all cases, if a methodology that can verify carbon savings from the above practices has been approved by the VCS board then those projects are eligible for VCS credits.

7.41 As with forestry and peat restoration projects, a key issue would be dealing with permanency which would need to be addressed through some form of insurance scheme (as outlined above for peatlands).

7.42 In the UK, first steps are being taken to introduce carbon accounting systems on farms which evaluate the impact changes in management could have on net emissions and sequestration. The Country Land and Business Association (CLA) recently supported joint research with the European Landowners Organisation, to look at ways in which rural estates can use carbon management to mitigate the causes of climate change (Viner, et al. 2006). The project developed a standardised methodology, based on the UK GHG Inventory, to measure an estate's 'carbon balance' called Carbon Accounting for Land Managers (CALM). This records an estate's energy and fertiliser use and cropping and livestock production to calculate total greenhouse gas pollution (in carbon equivalents). The methodology then calculates the amount of carbon stored in the estate's carbon sinks and the resulting carbon balance enables land managers to assess what they can do to mitigate their emissions and enhance their removals.

7.43 The CALM methodology is an important first step in developing a robust and easy to use accounting system that will work at the farm scale. It now needs to be tested at a broader range of farm types and with other land managers, including foresters and in the nature conservation sector (for example on National Nature Reserves and other such sites).

Key evidence gaps

Emissions leakage/displacement

7.44 The issue of leakage is clearly an important one which requires full consideration and analysis when contemplating GHG reduction options for the land management sector. It is often cited as a reason to discount any mitigation options which require land to be taken out of intensive agricultural production

7.45 However, there does not appear to have been a lot of research into the both the likelihood and potential scale of leakage caused from changing land use in order to deliver GHG savings, particularly in the context of English agricultural production.

Reduced tillage

7.46 There has been some significant research into reduced tillage systems both globally and in the UK, but there remain some unanswered questions on the effectiveness and appropriateness of expanding reduced and no tillage systems in a UK context.

Increased organic returns

7.47 As with reduced tillage, some research has been undertaken but there is still a need to improve our understanding of the potential for increasing organic returns as a mitigation measure. For example, is there scope for compost to play a more significant role, especially recycling green waste from urban areas?

Extensification

7.48 This review has not found a large body of evidence on the role that extensification, especially the use of legumes instead of inorganic fertiliser, can play to reduce GHG emissions.

Organic systems

7.49 This review has not looked at this issue in detail, but it is recognised as needing more research as there is likely to be a relatively large body of available evidence (particularly globally).

Pond creation

7.50 There is a need for measurements to be taken of carbon accumulation in English farm ponds, to ascertain if the research in the USA is comparable. Pond Conservation are currently measuring sediment depth and carbon content from various constructed ponds in central England (Pond Conservation, 2008). Initial results have reportedly found rates of uptake which are broadly consistent with the US data ranging from 250 g C $^{m-2}$ per year to around 5000 g C $^{m-2}$ per year.

Carbon accounting systems

7.51 There is a clear need to continue and build on the pioneering work of the CLA with the CALM tool, in the development of a robust carbon accounting methodology which will be effective at the farm scale. Carbon accounting systems for land managers must include emission factors that account for GHG fluxes from the management of soils and biomass.

8 Coastal Systems

Current levels of carbon storage and greenhouse gas fluxes

Plate 9 Eroding saltmarsh and mudflat in the Blackwater estuary, Essex

8.1 At a global scale, the soils of tidal salt marshes and mangrove swamps sequester at least 44 MtC a year from the atmosphere (Chumra, 2004). In a UK context, burial of organic rich sediments within estuaries acts as a sink for carbon, nitrogen and phosphorus (Shepherd and others. 2005).

8.2 However, consideration of methane and nitrous oxide fluxes is necessary in order to determine whether coastal wetlands act as a net greenhouse gas source or sink (Chumra, 2004). For example, the degradation of organic carbon within the organic rich sediments can exhaust available oxygen, allowing the process of denitrification which can be a significant source of nitrous oxide (Shepherd and others, 2005).

8.3 There does not appear to be a significant amount of research that quantifies the estimated amount of carbon stored in UK coastal systems, the rate of sequestration (or 'sedimentation') for saltmarsh and other intertidal habitats and the overall flux of greenhouse gases from estuarine systems.

8.4 Similarly, there appears to be minimal understanding of the amount of carbon that is being lost from coastal habitats as they erode in response to sea level rise and other pressures. However, research in the Humber estuary has shown that the loss of intertidal habitats has markedly reduced the trapping of organic carbon (Shepherd, and others, 2005).

Practices that can reduce CO_2 emissions and /or enhance sequestration

Plate 10 Tidal channel through saltmarsh

8.5 It is possible that managed realignment could enhance carbon storage and sequestration by coastal systems. By allowing, as much as possible, for natural processes to guide a changing coastline there could be opportunities for the significant creation of new habitats. This could be delivered directly through breaches of existing coastal defences, or through changes to land management behind sea walls to wet up land, create fen conditions and stop further carbon loss through oxidation of former saltmarshes now under arable cultivation.

8.6 Research in the Blackwater estuary estimated that between 0.44 and 1.77 t/C/ha a year could be stored from the creation of intertidal habitat (Shepherd and others, 2005). The issue of managed realignment is often very sensitive, especially for those communities directly affected by coastal erosion. However, the carbon (including CH_4) implications of managed realignment may not have had significant consideration in this debate up to now (Dixon and others, in press).

Implications for the natural environment

8.7 The maintenance, restoration and creation of inter-tidal habitat will generally be beneficial for coastal biodiversity and for building more resilient coastal systems in the face of rising sea levels.

Viability for inclusion in carbon markets

8.8 As with peatlands, there are currently no methodologies in place that can verify the carbon savings delivered from coastal habitat creation and/or maintenance.

8.9 Our overall understanding of the role of coastal systems in carbon storage and sequestration is relatively poor, especially when compared to the evidence base for other ecosystems and land uses.

Key evidence gaps

Area of inter-tidal habitat and carbon storage in England

8.10 There is a need to undertake an analysis that will quantify the total area of intertidal habitat in England that is capable of sequestering carbon when in good condition and the total amount of carbon stored in these habitats.

Research into accumulation/sequestration rates and GHG fluxes from inter-tidal habitat

8.11 There is minimal understanding of average accumulation rates for intertidal habitat and the contribution that maintenance, restoration and creation of these habitats by land management makes to carbon sequestration.

8.12 More research is also required into understanding the GHG fluxes from intertidal habitats, both when in good condition and when unfavourable.

9 Marine

Current levels of carbon storage and greenhouse gas fluxes

9.1 Oceans represent the largest carbon sink on the planet, accounting for some 30 - 50% of carbon fixation each year, and over geological times closer to 90%. It is estimated that the oceanic sink sequesters 0.7 billion tonnes of carbon per year (Le Quéré and others, 2007).

9.2 Carbon is sequestered and stored in oceans through the mass effect of the primary productivity of the tiny phytoplankton in the surface layers, as well as the fixation ability of particular habitats such as sea grass beds, coral reefs and muddy seabeds.

9.3 Research by the Global Carbon Project in 2007 (Le Quéré and others, 2007) has recorded a 30% decrease in the efficiency of the global oceanic sink. This is likely to have been caused by strengthening of the winds around Antarctica which enhances ventilation of natural carbon-rich deep waters. The strengthening of the winds is itself attributed to global warming and the ozone hole (Le Quéré and others, 2007).

9.4 The progressive acidification of oceans due to increasing atmospheric carbon dioxide is expected to have negative impacts on marine shell-forming organisms (for example, corals) and their dependent species. By 2100, ocean pH is very likely to be lower than at any time during the last 20 million years (IPCC, 2007). This trend is very likely to affect the sequestration ability of the ocean carbon sink.

Practices that can reduce CO_2 emissions and /or enhance sequestration

9.5 Relatively little recognition is currently given to the potential role marine managers can play as carbon managers in global or UK climate mitigation policy

9.6 A key management practice which will maintain and enhance carbon storage and sequestration is the zoning of marine areas to protect against adverse pressures, such as over-fishing, dredging or pollution

9.7 Marine Protected Areas (MPAs) represent a potentially useful ideal tool through which to achieve effective management and are one of the more likely verification mechanisms that would be needed to ascertain if carbon management is being achieved.

Implications for the natural environment

9.8 Investigating the carbon management role of marine ecosystems can be seen as a logical extension of initiatives that already focus on building marine ecosystem resilience and resistance to climate change.

Viability for inclusion in carbon markets

9.9 As with peatlands, there are currently no methodologies in place that can verify the carbon savings delivered from coastal habitat creation and/or maintenance.

9.10 Our overall understanding of the role of coastal systems in carbon storage and sequestration is relatively poor, especially when compared to the evidence base for other ecosystems and land uses.

Key evidence gaps

Scientific understanding of marine carbon cycle

9.11 The science behind marine carbon sinks requires more research, particularly understanding what factors cause a marine carbon sink to become a source?

Improve understanding of implications of management on marine carbon cycle

9.12 More research in needed to understand where the best potential for management intervention is from a carbon perspective. Is it possible to determine if current Marine Protected Area actions are already delivering GHG benefits?

9.13 An assessment of the GHG contribution of no-take zones, which are already well documented in increasing biomass and habitat complexity, would be useful. Is there a net uptake effect or a carbon redistribution issue from neighbouring areas?

10 Key Findings, Next Steps and Natural England's Contribution

Key findings

10.1 This review has identified five key findings which are summarised below:

1) **Peatlands are England's most important carbon store**. However, peatlands also emit significant amounts of CO_2 when they are degraded. This report has estimated that in England's lowland fens alone, degraded peatlands could release between **2.8 and 5.8 million tonnes** of CO_2 each year. This is significantly higher than is currently recorded in the UK's formal Greenhouse Gas Inventory, which does not even account for any further potential carbon losses from degraded peat bogs in England's uplands.
2) **Peatland restoration will reduce carbon losses**. However, there is a need for more information on how much methane is emitted from restored peatland sites. Methane is a more potent greenhouse gas than CO_2, and will reduce or counteract carbon savings in some situations. More research is needed to establish the greenhouse gas benefits of restoration before carbon revenues could be generated on a large scale.
3) **Woodlands make the most important contribution to CO_2 sequestration in the UK**. The evidence suggests that bringing neglected woodlands into management for bio-energy and low-carbon products will deliver more carbon benefits than widespread tree planting. New markets for wood products could also generate additional income streams for farmers while increasing biodiversity.
4) **Increasing carbon storage in agricultural soils has limited potential** - practices that could make a contribution include changing tillage (for example adopting farming techniques where the land is not ploughed or turned), increasing organic returns (applying farmyard manure and other organic matter to increase the soil's organic carbon) and taking some land out of cultivation (including allowing buffer strips at the edges of fields). However, the evidence that permanent greenhouse gas benefits can be gained from such changes is weak. Consideration of the extent to which food production could be displaced also needs to be taken into account.
5) **Coastal and marine ecosystems are vital global carbon stores** - but we do not currently have sufficiently strong evidence on the carbon benefits from maintaining, restoring and creating these habitats. More research is required before this potential can be quantified.

Accounting for emissions from peatlands in the UK GHG Inventory

10.2 This review has identified that the UK GHG Inventory appears to be under-recording GHG emissions from managed peatlands, mainly due to under-estimating the area of peatlands.

10.3 The UK GHG Inventory accounts for CO_2 emissions from lowland peat drainage and peat extraction. The combined CO_2 emissions from both sources is recorded as 1.57 $MtCO_2$ per year for the whole of the UK (1.15 $MtCO_2$ from lowland peat drainage and 0.42 $MtCO_2$ from peat extraction).

10.4 In order to calculate CO_2 emissions from lowland fen, the Inventory estimates that approximately 150,000 hectares have been drained in England, of which 145,000 hectares is in the East Anglian fens and a further 5,000 hectares in the rest of England, all of which is assumed to be cultivated.

10.5 Analysis by Natural England indicates that the total area of deep peat in England alone is much higher than recorded in the Inventory, at around **680,000** hectares. This report estimates that, using the UK GHG Inventory emission factors, English lowland peatlands could be emitting between **2.8 and 5.8 million tonnes** of CO_2, which exceeds higher profile sources, such as domestic aviation (2.47 $MtCO_2$) and is on a level with emissions from UK cement production (5.42 $MtCO_2$).

10.6 The Inventory does not calculate emissions from upland blanket bog despite the majority of the resource being drained and with significant areas (especially in the southern Pennines) severely gullied, eroded and de-vegetated. Furthermore, the approach taken to calculating emissions from peat extraction do not account for the drainage required prior to and during the extraction process, which suggests that the figure of 0.422 $MtCO_2$ is also an under-estimate.

10.7 For these reasons, it is highly likely that the UK GHG Inventory is under-recording CO_2 emissions from managed peatlands.

Evidence for GHG benefits from peatland restoration

10.8 Restoration of the hydrology of damaged peatlands will reduce losses of CO_2, but this practice is also likely to increase methane emissions. However, studies of a limited number of restored peatlands across Europe suggest that restoration will generally deliver a net greenhouse gas benefit, despite increasing methane emissions, due to the scale of CO_2 savings

10.9 More research is required on the impact of restoration on methane emissions from different peatlands to establish the GHG benefits of restoration, before these can be used to generate income from trading emissions savings on a wide scale.

CO_2 sequestration from woodlands

10.10 Woodlands have a vital contribution to make to climate mitigation, achieved primarily through improving their management and realising the potential of the existing resource, much of which is neglected.

10.11 Bringing farm woodlands back into viable economic production through developing new markets for woodfuel and wood products will deliver greenhouse gas savings through reduced use of fossil fuels and also deliver a wide range of other environmental and social benefits.

Changes to agricultural practices

10.12 Land managers can increase carbon storage in mineral agricultural soils, through practices such as changing tillage, increasing organic returns and taking some land out of active cultivation (for example buffer strips).

10.13 However, the evidence for the greenhouse gas benefits delivered from such management changes is relatively weak and often inconclusive. There are also other considerations, such as displacement of production, which could negate any greenhouse gas benefits.

10.14 As with peatland restoration, there is a potential opportunity for land managers to engage with carbon markets and develop new revenue streams from carbon management practices. The development of accurate carbon calculators, such as CALM, is a useful first step. It will also be necessary to develop verification methodologies for specific practices that are applicable in UK conditions. This will require improvements to the evidence base.

Potential contribution from coastal and marine ecosystems

10.15 Coastal and marine managers also have a potential contribution to make, but more research is needed to develop the evidence base.

10.16 Coastal habitats, such as saltmarsh and mudflats, are already recognised as playing an important role in nutrient recycling including for carbon. However, as with peat, these important habitats are vulnerable both to the direct impacts of climate change (ie from sea level rise) and in some cases to insensitive management and engineering responses. There is a lack of evidence on the current scale of carbon storage in UK coastal habitats. As with peat, there is a need to develop an approved methodology which will verify the GHG benefits from coastal habitat restoration and creation projects.

10.17 The potential from marine sequestration is vast, but not enough is known at the moment to develop any form of carbon management scheme. More research is required, especially focussing on the contribution marine protected areas can make to marine carbon storage and sequestration.

Next steps

10.18 Carbon management by land and marine managers can deliver some significant potential benefits for climate mitigation, adaptation and the provision of a range of ecosystem services. It also offers land and marine managers a potential new market opportunity.

10.19 To meet this potential, the following needs to be delivered:

Develop the evidence base

- There are a significant number of gaps that need to be bridged. A comprehensive research programme is needed, initially focussing on developing a range of robust, peer-reviewed emission factors for UK peatlands.

Develop engagement with the carbon markets

- Methodologies must be developed for verifying the GHG savings and sequestration delivered by land and marine based projects, particularly for peat restoration, agricultural soils and coastal habitats. Other criteria for generating carbon revenue must also be addressed, such as additionality, permanence, leakage and double-counting.

Raise the profile of carbon stores

- Policy makers and the agricultural/marine sectors need to be aware of the potential contribution carbon management can make to mitigation, as well as delivering a range of other benefits.

Integrate land use in carbon accounting

- Ensure that carbon accounting tools include emissions from land use and land use change, so that land managers are aware of the carbon implications and opportunities of management practices.

Natural England's contribution

10.20 Natural England is exploring how land and marine managers can be encouraged to conserve and retain carbon stores by investigating how to put a market price on securing and enhancing carbon.

10.21 Working with land managers and in partnership with other interested organisations; we aim to develop a robust and testable methodology for verifying carbon savings, initially from peatland restoration. We are working jointly with Defra and other partners in the national Peat Partnership Project to improve the evidence base on the current state of the peat resource and the measurement of carbon budgets for a range of peatland habitats.

10.22 We are assessing how we can enhance the contribution that our delivery of the Environmental Stewardship scheme makes to securing carbon stores and enhancing sequestration.

10.23 We have also jointly commissioned, along with Defra, Forestry Commission, and the Environment Agency, a comprehensive review of mitigation options available to the AFLM sector which will include an assessment of potential new policy mechanisms.

10.24 We are currently also undertaking a more detailed review of the potential for marine management practices to enhance CO_2 sequestration, which we aim to publish in spring 2009.

10.25 Finally, we are contributing to the development of on-farm carbon accounting tools for farmers land managers, working in partnership with representatives of the agricultural and land management sector.

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