Annex 1-

Spatial Prioritisation of Land Management for Carbon 2014

Released as part of context setting for:

Natural England Commissioned Report NECR510

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Catalogue code: NECR510

Foreword

This report has not previously been published when produced in 2014. This was due to data licence issues with this data restricting use to only Natural England Staff and not being possible to release this externally. We have added it here as useful background to the 2023 update of this data set which will be open data.

Forward to Spatial Prioritisation of Land Management for Carbon 2014

The Countryside Stewardship scheme aims to address climate change as a cross-cutting theme. This report highlights the potential to store carbon by adjusting delivery of land management options in some locations. This GIS data layer was created to help understand the best way to adjust agri-environment delivery spatially so that we can mitigate climate change.

Climate change is already affecting the natural environment (Terrestrial report Card 2015[1]), it is clear that to stay below 2 ^{o}C we would need to have reversed the upward trend of world CO^2 emissions by around 2015 and we are presently on an emission trajectory for at least 4 ^{o}C of warming. As such it is important that every sector does it's upmost to reduce emission, by using the data created within this report, it helps highlights where the natural environment can make the biggest contribution to sequestering carbon from the atmosphere or reduce further emissions when delivering Countryside Stewardship.

The development of this data set, along with this report, was as a result of developments made during the work to deliver *Developing Datasets for Biodiversity 2020: Outcome 1D* (NECR 214)[2].

Outcome 1D States;

'Restoring at least 15% of degraded ecosystems as a contribution to climate change mitigation and adaptation.'

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[1] https://www.ukri.org/publications/climate-change-impact-on-biodiversity-lwec-report-cards/

[2] Developing Datasets for Biodiversity 2020: Outcome 1D (NECR214)

The particular issues that needed to be grappled with when developing thinking around Outcome 1D were;

- What are the key locations or ecosystems in England to initially concentrate on that will deliver the best climate change adaptation and mitigation outcomes by 2020?
- What is a degraded ecosystem when applied to England?
- As the target specified to deliver at least 15% of the area. Then some way of developing a baseline around what has been degraded by 2010 would be needed, how best to do this pragmatically so delivery is effective by 2020.

The extent of baseline habitat potential for the target wetland and coastal ecosystems was calculated as about 3.6 million ha, or about 28% of England. Attempting to do 15 % of this area by 2020 was undeliverable in terms of resources, time and scale of the locations needed. As such the use of the Dudley Stamp Land Use Survey from the 1930's to look at change since this time created a more pragmatic solution of closer to 1 million Ha.

As part of this work a system was needed to understand the key locations for carbon mitigation delivery to direct this to the most beneficial places to deliver the 15% target. This concentrated on the area that had been highlighted (28% of England) from the previous baseline work.

When approaching this from a Countryside Stewardship targeting perspective, the whole area of England would be needed to get a true picture of the key locations for delivery. It also gave the opportunity to do a more in-depth literature and data review of this fast-developing subject, so basing the new outputs on the best current thinking.

When considering Carbon mitigation spatially two key aspects are present; Carbon Storage and Carbon Sequestration. The Storage element is the locations that have the most carbon rich soils presently (generally peatlands) and through advances in the present land management practices carbon storage can be maintained into the future. The Sequestration element highlights the areas losing the greatest amount of carbon to the atmosphere. Consequently, through an adjustment in land use to a lower emissions state, additional carbon can be stored through the application of the Countryside Stewardship options in these key locations.

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Keywords – Biodiversity 2020, ecosystems, degraded ecosystems, climate change, adaptation, mitigation, carbon storage, carbon sequestration, resilience, restoration, function, functional approach, ecosystems approach, wetland, coastal.

Further information

This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**.

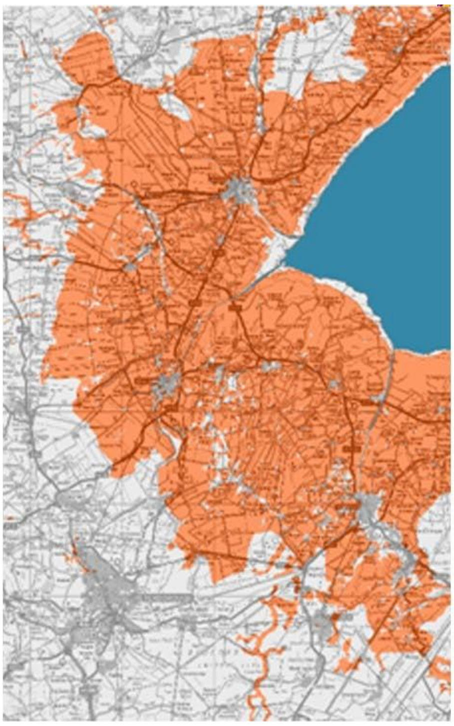
For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

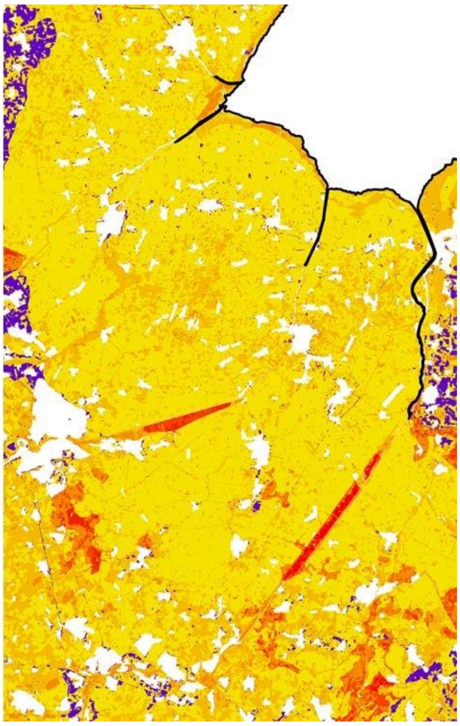
Please note: The rest of this report was compiled in 2014 and does not meet Natural England's current accessibility requirements.

Natural England

Spatial Prioritisation of Land Management for Carbon

Project Report (Final)





20 March 2014

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Document Revisions

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1	Incomplete draft report	03 March 2014
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Executive Summary

Introduction

Natural England, in conjunction with Defra and other stakeholder organisations, has recently reviewed the existing agri-environment options and capital items with the aim of developing a New Environmental Land Management Scheme (NELMS) taking into account the land use planning requirements of farming and food production, access and education, biodiversity, and the historic environment. The conclusions from the review are currently being used to develop the options and capital items for NELMS. NELMS will supersede all existing agri-environment schemes, namely the Environmental Stewardship (ES) and the Catchment Sensitive Farming (CSF) schemes. The draft proposals for the new scheme options will be available in late April/early May 2014.

The overall aim of the study presented in this document is to enable spatial prioritisation of land management and land use policy for carbon within the context of NELMS. This study (focusing on carbon) ran in parallel with, and has informed, the NELMS review that has recently been undertaken by Natural England. As part of the development of options for NELMS, Natural England has been compiling and amalgamating many hundreds of spatial datasets, including the Geographical Information System (GIS) outputs from this study.

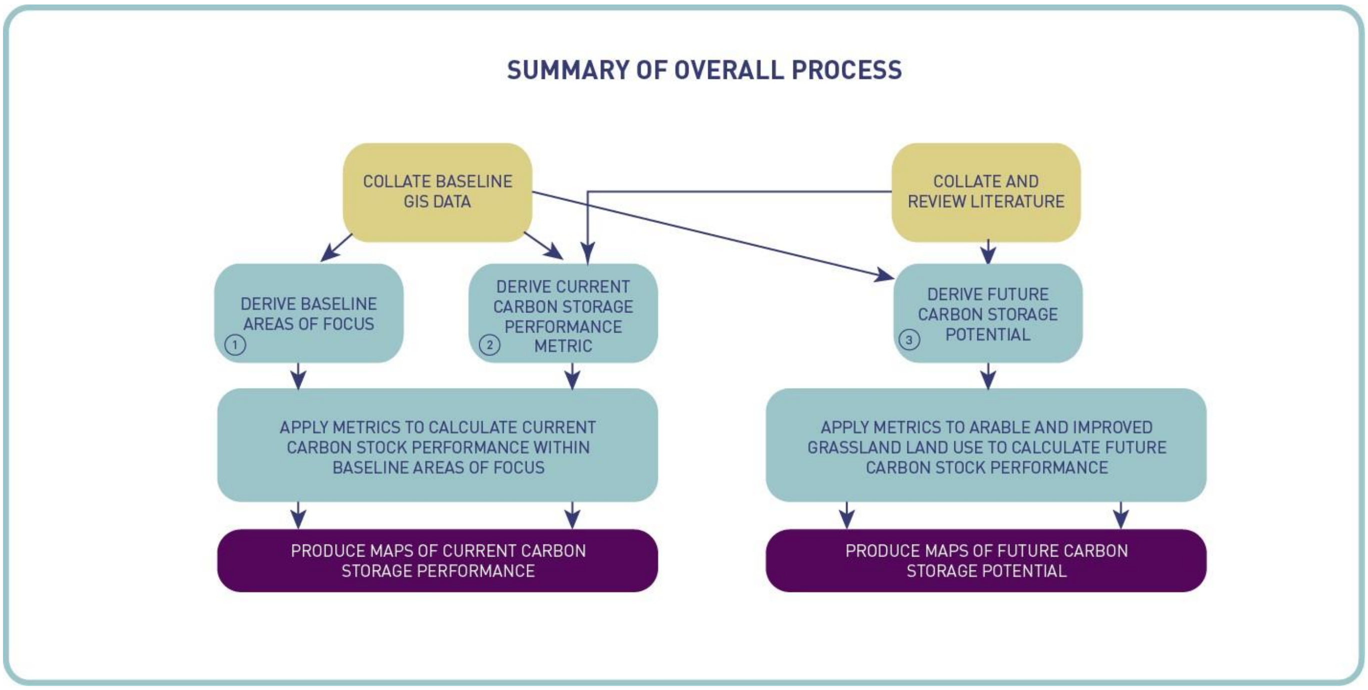
Approach

Fundamental to this study was a data collation and data quality review exercise undertaken by the AMEC project team to assess the suitability of datasets and literature relevant to and to be used in the study to; the aim being to identify the 'usefulness' and limitations of the datasets/literature in determining spatial prioritisation of land management and national land use planning for carbon. The study report highlights the characteristics of the most important datasets and literature collated, reviewed and used in the study and also describes how the characteristics of the datasets ultimately influenced the spatial resolution and accuracy of the final GIS layers produced in the context of the study objectives and what steps were taken (where possible) to account for these dataset limitations.
This ultimately shaped the scope of the study.

A metric-based approach was used to assign, using professional judgement and experience, numerical values on a relative scale to spatial/scientific data. The metrics were then used to refine, analyse and present the datasets within GIS. The study report describes how the baseline area of the study has been derived, how areas of greater current carbon storage performance have been identified and mapped and how areas of greater future carbon storage performance potential have been identified and mapped. Finally, the study report describes how spatial analysis was undertaken to compare the merits of a targeted versus a non-targeted approach to land use planning/change within NELMS.

The study report includes appendices that contain Project Workbooks showing the individual metrics that were derived, and which were used to undertake the GIS processing, and the spatial analysis and calculations that have been undertaken. The background research containing the results of the literature review which fed into the derivation of some of the metrics is also provided in the report.

A summary of the data collation and processing is provided below:



Key Findings

For land use decision making, it is clear that there is a trade-off to be made between targeting those habitats/soil types which may be extensive but have limited carbon density values and targeting those habitats/soil types which have high carbon density values but are limited in extent. This has important implications for decision making.

Based upon the example scenarios, and in order to maximise carbon storage per quantum of land available for action under NELMS (e.g. 100Ha), it is recommended that either:

Appendix A There is a targeted approach towards securing existing carbon resources associated with highest performing habitats (e.g. bog), by preventing further habitat degradation[3]; **OR**

Appendix B A ‘mixed’ targeted approach is adopted, whereby:

[3] However, there are other drivers for this – see Wetland Vision at http://www.wetlandvision.org.uk/

- further degradation of existing semi-natural habitats with good carbon storage is prevented.
- whilst **ALSO** ensuring that existing agricultural land uses are changed to semi-natural habitats.

However, given that the extent of land under arable or improved grassland in England constitutes 1 173 875 Ha (50% of all land use), clearly there is a great opportunity to deliver significant carbon storage benefits.

Further research on the carbon balance consequences of restoring wetlands (peatlands) is still needed and the timescales for realising GHG benefits from restoring wetlands could be hundreds of years AMEC's analysis of the datasets used in this study shows that Soilscapes beneath mire (peatland) habitats[4] are the highest performing in terms of carbon density, but these Soilscapes only account for <3.5% (388 192 Ha) of the total extent (area) of the UK. Taking into account carbon density in vegetation AND in soils by habitat type, coniferous and deciduous woodland seem to hold the greatest carbon density of any habitat per hectare, compared to, for example, fen and bog (Alonso *et.al*, 2012).

Calculations by AMEC for this study suggest that conversion of arable or improved grassland to woodland/forestry could result in the capture of up to an additional 3.73 t C/ha, which equates to 3 730 tonnes of carbon for every 100 ha over 10 years (see Section 3.3). Assuming only 1% (11 739 Ha) of available agricultural land currently under arable and/or improved grassland is given over to woodland/forestry, then that equates to an increase in carbon density (storage) of up to 437 864 tonnes of carbon over 10 years.

Project Uncertainties

Invariably, any study that uses large national datasets and a large component of subjective professional judgement could be appreciably constrained. However, whilst undertaking this study, the project team has been acutely mindful of the limitations that were present in the datasets or methods used and where possible, steps were taken to account for these and acknowledge these limitations with the project steering group. The GIS datasets used were large national datasets which invariably had various limitations/characteristics around spatial accuracy, resolution and data quality however steps were taken to address these where possible, as described in the report.

[4] Raised bog soils, blanket bog soils, fen peat soils.

From the literature review, it became apparent that it was not possible to establish, with any confidence, a clear and consistently comparable picture of carbon density and carbon balance (GHG/carbon emissions/sequestration) for distinct habitats for various reasons, principally lack of data and consistency in the way in which data was presented. For example, it is not clear why 'arable to forestry' over 115 years sequesters less carbon per hectare than 'improved grassland to woodland' over 20 years. There also appears to be a large discrepancy (two orders of magnitude) between carbon density values for highest performing soils as given in Natmap Carbon
(i.e. 1 880 t C/ha which relates to raised bog soils) and higher performing habitats (i.e. bog at 76t C/ha; see Alonso *et.al*, 2012) in the literature. This discrepancy may be because the literature values only relate to a soil depth of 0.5 m, whereas Natmap Carbon values go to a depth of 1.5 m, taking in more carbon resource at depth, but such discrepancies require further rationalisation by sector experts.

Furthermore, dissolved organic carbon (DOC) losses from soil to the fluvial system would need to be considered to get a complete carbon balance picture but no data relating to specific habitats was identified.

Theoretically there could be 'double counting' of having two iterations of land use weighting being applied to carbon density values and used to derive some of the metrics, once within the Natmap Carbon dataset and then again using the LCM2007 data. However, it is considered that this potential limitation is far outweighed by the benefits of being able to derive metrics that more accurately reflected land cover on the ground to a finer detail (land parcels) and to take account of land cover change.

Professional judgement and experience were used to assign the metric values to various attributes within the datasets used which invariably introduced subjectivity. However, the assignment of metrics was quality reviewed by the project steering group.

Current Carbon Storage Performance values are, or are seemingly shown, as 'low' (are green or yellow) on the study report output maps around areas such as the Cambridgeshire Fens and Humber Peatlands because although certain regions may score high for carbon storage; the overall score is then downgraded by the fact that there is currently a spatial abundance of arable/improved grassland and that historically there has been a spatial abundance of arable/improved grassland. Alternatively, in some regions, some higher performance areas (shown as orange on the maps) are indeed present, it is just that the finer detail is lost at the resolution the map is viewed (national scale at A3 size).

With regards to the calculations undertaken for targeted versus non-targeted scenarios of capturing more carbon for a quantum of land (100 Ha), the calculations are subjective, based upon many assumptions and involve many of the data discrepancies describe above. In addition, only one literature source was located that provided data on carbon sequestration due to land use changes for certain habitats/land uses (Alonso *et.al*, 2012).

There is therefore limited confidence in scaling up 'additional carbon sequestered' values per hectare to 'predicted future carbon stock values' for large geographical areas due to habitat changes, and the calculations and results are to be treated with caution.

Suggestions

In the above context, and based upon the analysis presented in this report, it is recommended that conversion of arable or improved grassland to woodland seems to be the most pragmatic solution for increasing carbon storage over short to medium timescales, augmenting work that is being done across the country under different policies and drivers to restore/create wetlands (peatlands)[5] for realising benefits over longer timescales.

It is also recommended that further research or rationalisation of existing values and value discrepancies between datasets/literature by sector experts is needed for the carbon balance consequences of changing from one specific habitat to another because currently the values are contradictory and not comparable.

For further research, maintaining the same set of parameters (consistent soil depth, management, timescales, vegetation plus soil) to allow direct comparisons to be made with confidence is recommended. The results could be used to refine the analysis work undertaken in this study.

[5] See Wetland Vision at http://www.wetlandvision.org.uk/

Contents

Background

Climate Change Adaptation and Land Use

The English landscape and its inherent habitats and ecosystems have been dramatically shaped by the naturally fluctuating climate and anthropogenic human activity that has occurred for thousands of years. However, the extent and pace of change has been considerably more dramatic since around 1750 following key historical events in human history, including the agricultural and industrial revolutions, both World Wars, and post-war development when agricultural intensity, productivity and significant changes in land-use occurred. More recently, this pace of change has been accelerated further by climate change.

The introduction of nature conservation legislation, biodiversity policies and agri-environment schemes over the last 30 years to strike a balance between more sustainable land use, food production and biodiversity has gone a considerable way to redressing the changes that have occurred (e.g. the success of agri-environment schemes as reviewed in Natural England, 2009).

Nonetheless, it is widely acknowledged that more needs to be done, and it is now widely accepted by statutory bodies and practitioners that climate change is one of the major drivers of profound effects on agriculture and forestry, business industries and services, the health and wellbeing of people, the natural environment and infrastructure (Smithers *et.al*, 2008; Lawton, 2010; Defra, 2011; University of Hertfordshire, 2011; HM
Government, 2012; Natural England, 2012; Burns *et. al*, 2013). The English landscape requires a more sustainable and holistic approach to land use planning to ensure that the cultural, historical, socio-economic and ecological landscapes and the people that depend upon that landscape, can adapt and mitigate (to some degree) the effects of climate change (Smithers *et.al*, 2008; Lawton, 2010; Defra, 2011; University of Hertfordshire, 2011; HM Government, 2012; Natural England, 2012; Burns *et. al*, 2013).

Subsequent to the *Making Space for Nature* report, and recognising the requirement for EU Member States to implement the targets and actions of the EU 2020 Biodiversity Strategy within their respective countries,
*Biodiversity 2020 (*Defra, 2011*)* outlines the Government's strategy for biodiversity conservation in England, with a series of outcomes to be achieved by 2020. Outcome 1 states that:

> "By 2020 we will have put in place measures so that biodiversity is maintained and enhanced, further degradation has been halted and where possible, restoration is underway, helping deliver more resilient and coherent ecological networks, healthy and well-functioning ecosystems, which deliver multiple benefits for wildlife and people..."

Investing in the improvement of wildlife and habitats can also improve the quality of life of people in many ways; achieving benefits for people alongside biodiversity conservation is consistent with the central theme of the government's Natural Environment White Paper 'The Natural Choice – securing the value of nature' (HM Government, 2011) and builds on Defra's "*Delivering a healthy natural environment: An update to 'Securing a healthy natural environment: An action plan for embedding an ecosystems approach*" (Defra, 2010).

The Government published the UK Climate Change Risk Assessment (CCRA) on 25 January 2012 (HM Government, 2012); the first assessment of its kind for the UK and the first in a 5 year cycle under which both the
CCRA and a National Adaptation Programme (NAP) will be revisited every 5 years. The NAP sets out the Government's objectives, proposals and policies for responding to the risks identified in the CCRA.

The CCRA sets out the main priorities for adaptation in the UK under 5 key themes identified in the CCRA 2012
Evidence Report - Agriculture and Forestry; Business, industries and Services; Health and Wellbeing; Natural Environment and Buildings and Infrastructure - and describes the policy context, and action already in place to tackle some of the risks in each area. The Government's response is outlined in five key steps in Box 1.1.

• **Box 1.1 The Government's Response to Climate Change (CCRA) (HM Government, 2012)**
• Minimise the risk of significant climate change; • Accept that despite efforts to reduce greenhouse gas emissions, current and historic emissions mean that a certain amount of warming is inevitable; • Better understand vulnerability to our current climate; • Use the best science and evidence to understand the range of climate changes we might face, and what effect they might have on our economy, environment and society (i.e. the CCRA); • Assess – using a risk-based approach – what we can put in place now, and plan for in the future, to increase the resilience of our economy, environment and society.

Although the CCRA has shown that, due to climate change, there is the potential for profound impacts on the level of productivity and product quality for both the Agriculture and Forestry sectors, given that collectively the Agriculture and Forestry sectors are responsible for managing approximately 90% of UK land (HM Government, 2012) opportunities exist to deliver cross-compliant benefits to nature conservation, food productivity, and climate change adaptation and mitigation.

Terrestrialised wetlands that accumulate peat ('peatlands') represent an important long term sink for atmospheric carbon dioxide (CO_2) and have the potential to moderate concentrations of atmospheric CO_2, albeit many peatlands in the UK have been disturbed (e.g. by drainage and agricultural improvement) (Worrall *et.al.*, 2011). This disturbance can significantly alter carbon cycling such that peatlands can become a source for (emitter of) greenhouse gases to the atmosphere (including CO_2)

and carbon particulates such as dissolved organic carbon (DOC) into aquatic ecosystems (Worrall *et.al*. 2011).

Clearly therefore, within the framework of an appropriate agri-environment strategy, there is an opportunity for agricultural land management to maintain (protect) existing carbon stocks and enhance carbon storage, helping the English landscape to become adaptable to, and mitigate some of the effects of, climate change, as noted in Hagon *et.al.* (2013).

Future Land Use Planning and NELMS

Natural England, in conjunction with Defra and other stakeholder organisations, has recently reviewed the existing agri-environment options and capital items with the aim of developing a New Environmental Land Management Scheme (NELMS) taking into account the land use planning requirements of farming and food production, access and education, biodiversity, and the historic environment.

The conclusions from the review are currently being used to develop the options and capital items for NELMS.
NELMS will supersede all existing agri- environment schemes (the Environmental Stewardship (ES) and the Catchment Sensitive Farming (CSF) schemes). The draft proposals for the new scheme options will be available in late April/early May 2014.

Further information is available at: http://www.naturalengland.org.uk/ourwork/farming/funding/nelms.aspx

Study Scope and Objectives

The overall aim of the study is to enable spatial prioritisation of land management and land-use policy for carbon within the context of NELMS.

This study (focusing on carbon) has run in parallel with and has informed the NELMS review that has recently been undertaken by Natural England (see Section 1.1). As part of the development of options for NELMS, Natural England has been compiling and amalgamating many hundreds of spatial datasets, including the Geographical Information System (GIS) outputs from this study.

The final scope of the work undertaken has changed markedly from that originally commissioned and was developed in conjunction with the project Steering Group. This was in response to the datasets and literature available and their inherent limitations/knowledge gaps (see Section 2.2), and the timescales and budget for the study.

The key final objectives of this study were to:

Appendix C Undertake a review of recent scientific literature (after Milne and Brown, 1997) to confirm the factors affecting carbon storage potential in soils;

Appendix D Establish a baseline area (extent) within England to be the focus of the study;

Appendix E Identify and map current carbon storage performance, highlighting areas of high carbon density that require protection to prevent further carbon losses/or avoid becoming carbon sources;

Appendix F Identify and map future carbon storage potential areas where carbon storage could be increased due to positive land use changes;

Appendix G Discuss the implications of the study and recommendations for land use planning in the context of NELMS and greenhouse gas emissions.

Purpose of This Report

To address the objectives outlined above, this report describes:

Appendix H The data reviewed for use in this project (Section 2.2);

Appendix I The approach to, and outcome of, the derivation of the baseline area for the study (Study Stage 1) (Section 2.3);

Appendix J The approach to, and outcome of, the identification and mapping of current carbon storage areas (Study Stage 2) (Section 2.4);

Appendix K The approach to, and outcome of, the identification and mapping of future carbon storage potential (Study Stage 3) (Section 2.5);

Appendix L The approach to, and outcome of comparing a targeted versus non-targeted approach to increasing carbon storage via NELMS for a quantum of land (100 ha);

Appendix M The implications and recommendations for land use planning in the context of NELMS and greenhouse gas emissions (Section 4); and

Appendix N References (Section 5).

A GIS project has been produced and supplied to Natural England as an output from this project.

It is envisaged that the report, output maps and GIS files will be used by the national and regional teams of Natural England to help focus local and regional nature conservation action on the ground to those areas in which action would be most beneficial in respect of carbon storage protection/enhancement. These actions would be expected to form part of an overall co-ordinated national strategy on land use planning, including NELMS.

Terminology

Various terms are used interchangeably within the literature, particularly the term 'carbon stock'. For example, 'carbon stock' has been used in the literature to represent:

Appendix O The total soil carbon resource (which is the definition used in this study);

Appendix P Soil organic carbon per depth interval (which in this report is 'soil organic carbon'); or

Appendix Q A measure of carbon in a soil profile per unit area (which in this report is 'carbon density').

Therefore, for the purposes of this study the definitions provided in Box 1.2 are used.

• **Box 1.2 Carbon Terms and Definitions Used in this Study**
• **Soil organic carbon (SOC)**: a measure of the carbon stored within organic matter in the soil. Expressed as a percentage (%); • **Bulk density**: a measure of soil compaction (the dry weight of soil per unit volume of soil). Bulk density considers both the solids and the pore space. Expressed as g/cm^3 (grams per centimetre cubed); • **Carbon density**: a measure of carbon in a soil profile per unit area. Calculated by multiplying bulk density and soil organic carbon. Expressed as Kg C/m^2 or t C/ha (Kilograms of carbon per meter squared or tones of carbon per hectare). For consistency, all carbon density values presented in this report are provided in both units of measurement (Kg C/m^2 and t C/ha); • **Carbon stock/resource**: Refers to the total soil carbon resource in a given geographical region (e.g. England). Typically expressed as Mt C (Megatonnes of carbon); • **Greenhouse Gases (GHGs)**: Gases in the atmosphere which cause global warming. They include carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). CO2 is the main greenhouse gas, but CH4 and N2O are the key emissions from the agricultural sector; • **CO2e (aka as C02-eq or CO2-e)**: Is shorthand for carbon dioxide equivalent and represents a standardised measure of global warming potential. This is a way of expressing the impact of all the different greenhouse gases as a single number because one molecule of CH4 or N2O has a greater warming effect than one molecule of CO2. Over a 100-year timescale, methane is 25 times more powerful at warming the planet than CO2, so 1 tonne of methane emitted can be expressed as 25 tonnes CO2e. Nitrous oxide has an even greater warming effect over a 100 year timescale and a tonne of this gas could be expressed as 298 tonnes CO2e; • **Carbon sequestration**: The process of removing carbon dioxide from the atmosphere and storage in another system such as vegetation; • **Carbon storage**: The process of 'locking up' carbon in the soil profile; • **Carbon sink**: If the carbon dioxide sequestered is more than the carbon dioxide emitted, the store is increasing and is known as a carbon sink;

• **Box 1.2 Carbon Terms and Definitions Used in this Study**
• **Carbon source**: If a system is emitting more carbon to the atmosphere than it is sequestering, it is known as a carbon source; • **Carbon balance**: The process of describing the rate per area per year at which carbon dioxide equivalents are either released (emitted) into the atmosphere or sequestered (captured) from the atmosphere. Expressed as t CO2e ha/ yr (tonnes of carbon dioxide equivalents per hectare per year). A negative number indicates carbon is being sequestered (captured) from the atmosphere, whilst a positive number indicates carbon is being emitted to the atmosphere. Notes: Definitions taken from or based upon Milne and Brown (1997); WCA (2009), Natural England (2010) Worrall et.al. (2011) and Hagon et.al. (2013).

Defining Current and Future Carbon Storage

Overview

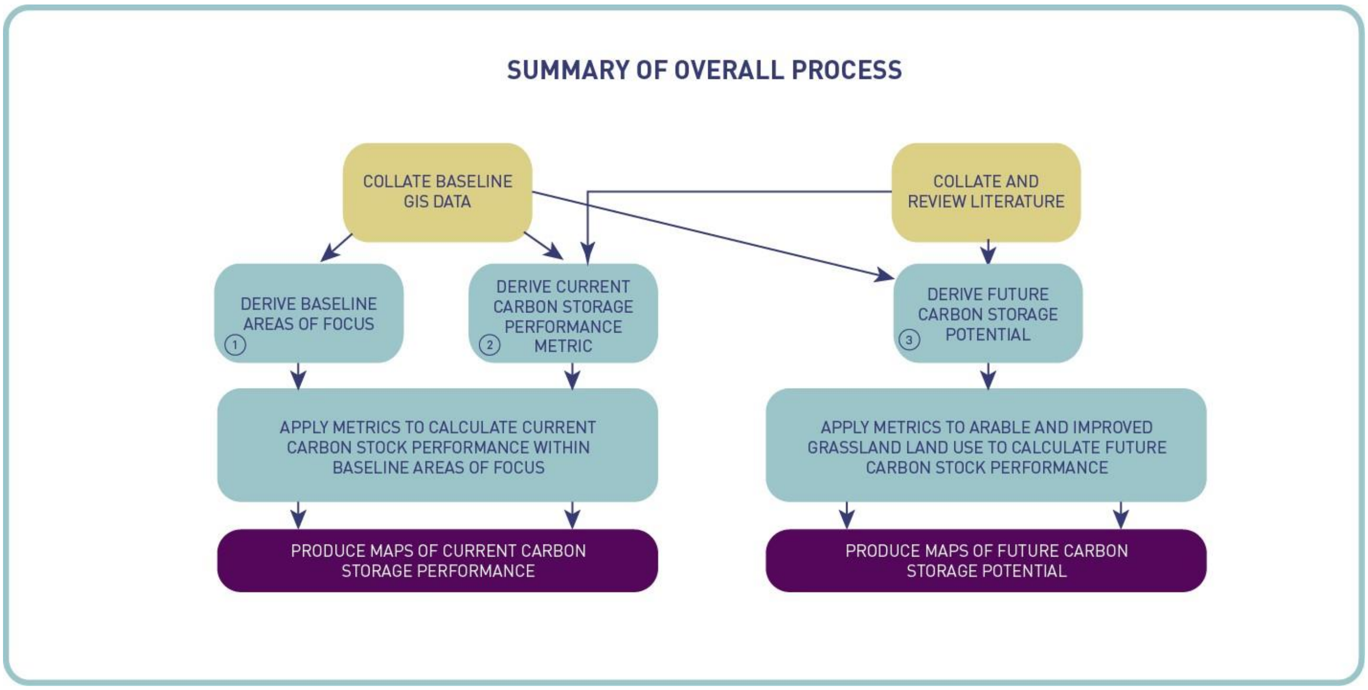
Fundamental to this study was a data collation and data quality review exercise undertaken to assess the suitability of datasets and literature relevant to, and to be used in, the study. The key aim of the review was to identify the 'usefulness' and limitations of the datasets/literature in determining spatial prioritisation of land management and national land use planning for carbon. Section 2.2 highlights the characteristics of the most important datasets and literature reviewed and used in the study. Section 2.2 also describes how the characteristics of the datasets ultimately influenced the spatial resolution and accuracy of the final GIS layers produced in the context of the study objectives, and what steps were taken (where possible) to account for limitations in these datasets. This ultimately shaped the scope of the study (Section 1.4).

Section 2.3 describes the approach to, and outcome of, the derivation of the baseline area for the study (Stage 1). Section 2.4 describes the approach to, and outcome of, the identification and mapping of current carbon storage areas (Stage 2). Section 2.5 describes the approach to, and outcome of, the identification and mapping of future carbon storage potential (Stage 3).

The steps undertaken to derive results for Stages 1, 2 and 3, using a metric-based approach are summarised in Plate 2.1 and in greater resolution on Figure 2.1.

The Project Workbook showing the individual metrics that were derived, and which were used to undertake the GIS processing are provided in Appendix A.

Plate 2.1 Overall Workflow



Data Collation and Review

Review of Published Literature

Many tens of document were reviewed, of which the following proved to be the most useful for informing the study, though recognising there were still information gaps:

Appendix R Alonso I, Weston K, Gregg R and Morecroft M, (2012). Carbon Storage by Habitat - Review of the Evidence of the Impacts of Management Decisions and Condition on Carbon Stores and Sources. Natural England Research Reports, Number NERR043;

Appendix S WCA (2009). *DEFRA PROJECT SP0567: Assembling UK Wide Data on Soil Carbon (and Greenhouse Gas Fluxes) in the Context of Land Management*. Report to Defra;

Appendix T Hagon S, Ottitsch A, Convery I, Herbert A, Leafe R, Robson D and Weatherall A, (2013). *Managing Land for Carbon*. Lake District National Park Authority;

Appendix U Natural England (2010). England's Peatlands – Carbon Storage and Greenhouse Gases.
Natural England Research Report 257. Natural England, Peterborough;

Appendix V Milne R and Brown T A, (1997). Carbon in the Vegetation and Soils of Great Britain.
Journal of Environmental Management No. **49**, 413–433;

Appendix W Worrall F, Chapman P, Holden J, Evans C, Artz R, Smith P and Grayson R, (2011). *A Review of Current Evidence on Carbon Fluxes and Greenhouse Gas Emissions from UK Peatland*.
JNCC Report, No. 442. JNCC, Peterborough.

Review of GIS Datasets, Data Quality and Usage

Ordnance Survey Boundary Line and Ordnance Survey Strategi Urban

The Ordnance Survey Boundary Line is the Ordnance Survey's core digital vector data product of administrative boundaries whilst the Ordnance Survey Strategi Urban is the Ordnance Survey's core digital vector data product for key urban settlements. Both have been used to limit spatial analysis and 'clip' and 'mask' datasets in GIS to the boundary of England and to 'remove/clip' urban and suburban areas to derive the baseline area for the study (Section 2.3), given the limitations of the Land Cover Map 2007 (LCM2007) (see below).

Although the resolution Ordnance Survey Strategi Urban dataset is coarse (spatial resolution of 1: 250 000 (i.e. 0.25 sq km grid squares)), compared to the better resolution afforded by Ordnance Survey 1:25 000 scale digital vector maps, the Ordnance Survey Strategi Urban represented a good workable solution for use in deriving the baseline area for the study, rather than the time that would have been required to batch process and stitch together individual 1:25 000 scale digital vector maps in GIS.

Landis Natmap Carbon (Soil Carbon Map)

The Landis Natmap Carbon dataset, from the National Soil Resources Institute (NSRI) at Cranfield University, is derived from the National Soils Map which in itself is based upon decades of soil surveys across the country. Average, minimum and maximum soil carbon density is given in Kg/m^2 at three different depth categories (0 to 30cm below ground level (bgl); 31 to 100cm bgl; 101 to 150cm bgl). Further detail on how the dataset was derived by NSRI is provided in Box 2.1 (from NSRI, 2014).

• **Box 2.1 The Landis Natmap Carbon dataset from NSRI (NSRI, 2014)**
"How was this map derived? For each soil series represented on the National Soil Map the organic carbon data held in the HORIZON fundamentals dataset was averaged across each of the 3 layers, the total stock in each horizon was calculated from the organic carbon and bulk density data taken from HORIZON hydraulics. The organic carbon data varies under different landuses and so the values for each soil series under arable, permanent grass and other landuses (mostly woodland or rough grazing) were separated. To interpret this on a soil association basis the mean carbon values for each component series was calculated, weighted by the proportion of each series in the soil association under the three landuses. The National Soil Map was then intersected with a landuse map dissolved from the Corine land cover 2000 map to just the 3 landuse classes required. Each polygon on the map was then linked to the carbon data with the relevant map unit and landuse combination" Further details at: http://www.landis.org.uk/data/nmcarbon.cfm

The Natmap Carbon dataset was a key input dataset used to develop a measure of current and future potential carbon storage performance. However, the dataset did have a number of limitations as described below:

Appendix X Coarse spatial resolution (1: 250 000 (i.e. 0.25 sq km) grid squares) compared to the other datasets (e.g. LCM2007);

Appendix Y The carbon units are spatially extensive within the dataset and only give one carbon density value for many different land use classes within the carbon unit. This limitation was identified by overlaying the LCM2007 dataset over the Natmap Carbon dataset and 'spot-checking' at several locations around the country including the Somerset levels and the south Lake District. It was therefore not possible to relate carbon density values to individual land parcels;

Appendix Z Although carbon density values have been adjusted by Corine land use class data[6], these land use classes are broad. It is believed that only four land use classes were used to adjust the actual carbon density values (urban, water, arable, other). No sub-divisions to these categories have been used;

Appendix AA It does not account for land use change.

In order to account for these limitations, it was necessary to use other datasets to assign carbon density values to individual land parcels (using LCM2007) and to give a measure of land-use change between the 1930 and 2007

[6] Pers.comm with LANDIS 12/02/2014.

(Dudley Stamp LUS and LCM2007) to derive 'Current Metric C' and 'Future Metric B'; see Section 2.4 and 2.5.

Landis Natmap Soilscapes

The NatMap Soilscape dataset is a simplified dataset derived by NSRI from the National Soils Map which in itself is based upon decades of soil surveys across the country. An interactive map is available at: https://www.landis.org.uk/soilscapes/.

The Soilscapes dataset was used to derive Future Metric A; an indication of carbon storage potential based upon soil type. However, the Soilscape dataset is only available at a relatively coarse spatial scale (1:250 000) and this is reflected in the scale of the individual habitat potential layers produced in the study.

The 27 Soilscapes are provided in Plate 2.2.

Plate 2.2 Landis Natmap Soilscapes

Soilscape ID	Description
100	Saltmarsh soils
200	Shallow very acid peaty soils over rock
300	Shallow lime-rich soils over chalk or limestone
400	Sand dune soils
500	Freely draining lime-rich loamy soils
600	Freely draining slightly acid loamy soils
700	Freely draining slightly acid but base-rich soils
800	Slightly acid loamy and clayey soils with impeded drainage
900	Lime-rich loamy and clayey soils with impeded drainage
1000	Freely draining slightly acid sandy soils
1100	Freely draining sandy Breckland soils
1200	Freely draining floodplain soils
1300	Freely draining acid loamy soils over rock
1400	Freely draining very acid sandy and loamy soils
1500	Naturally wet very acid sandy and loamy soils
1600	Very acid loamy upland soils with a wet peaty surface
1700	Slowly permeable seasonally wet acid loamy and clayey soils
1800	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils
1900	Slowly permeable wet very acid upland soils with a peaty surface
2000	Loamy and clayey floodplain soils with naturally high groundwater
2100	Loamy and clayey soils of coastal flats with naturally high groundwater
2200	Loamy soils with naturally high groundwater
2300	Loamy and sandy soils with naturally high groundwater and a peaty surface
2400	Restored soils mostly from quarry and opencast spoil
2500	Blanket bog peat soils
2600	Raised bog peat soils
2700	Fen peat soils

Dudley Stamp Land-Utilisation Survey (LUS) Land Use Map

The first Land-Utilisation Survey (LUS) of Great Britain, directed by Professor L. Dudley Stamp, was a key dataset in the study, because it allowed a measure of land use change between 1940 and 2007 to be described (in conjunction with the LCM2007).

This survey created the first detailed record of the major land uses in England, Wales and southern Scotland and was published as a set of 169 map sheets. 135 of these maps covered England and

Wales, using Ordnance Survey 1” maps as a base, and displaying land uses via a colour overlay. The 1940 baseline date used in the study, in part, reflects the availability of this dataset.

In 2003, a project was funded by Defra to source, scan, geo-reference and disseminate the full set of the published LUS maps of Great Britain (Southall *et.al.,* 2003). However, these maps were only available as scanned images and could not be used to undertake GIS based analysis of land use change.

To address this limitation of the data sources, the Environment Agency commissioned a study in 2009 to develop a method to systematically extract land-use information from the scanned LUS images (reported in Entec, 2010). This method was used to classify a series of example map sheets across England and Wales and outputs were externally reviewed by the Environment Agency and Natural England. This quality assessment formally approved the method produced and led to final classification of the remaining images for England and Wales. An illustration of the output from the study is provided in Plate 2.3.

Plate 2.3 Land-Utilisation Survey (LUS) Dudley Stamp – Illustration of the Translation Process

Although this dataset is presented as a seamless dataset, it is important to note that the quality of the scanned 1” base maps from which it was derived were variable. This variability contributes to spatial differences in the overall accuracy of the information contained in the final GIS dataset and ultimately the accuracy of the 1940-2007 land use change GIS layer and ultimately the final degraded habitat metrics (‘Current Metric C’ and ‘Future Metric B’; see Section 2.4 and 2.5).

CEH Land Cover Map 2007 (LCM 2007)

The Centre for Ecology and Hydrology (CEH)'s Land Cover Map (LCM) 2007 was a key dataset in the study, for two principal reasons: 1) it was the dataset with the finest scale of resolution (25 m^2 (i.e. 2.5e-005 sq km) grid squares) to which all other datasets could be cross-matched and scale down to; and 2) it allowed a measure of land use change between 1940 and 2007 to be identified (in conjunction with the Dudley Stamp LUS).

The LCM2007 dataset was produced by remote sensing/image processing of over 70 satellite images taken in 2007 covering the entire UK and which were combined into 34 multi-date summer-winter images. These images were classified using a variety of image processing technique. This processing resulted in the development of a series of products, including the standard 25 m^2 raster product containing 23 land use classes, plus an accompanying vector parcel-based products containing 10 detailed attributes. The dataset was released in 2011 by CEH (see Morton *et.al* (2011) for further detail). Although the outputs of the image processing were subject to sampled quality review, the quoted accuracy of the final classification product is about 83% (based upon field validation of 9127 points) (CEH, 2011). This is an additional factor which influences the accuracy of the spatial distribution of the 1940-2007 land use change GIS layer, and ultimately, the final degraded habitat metrics ('Current Metric C' and 'Future Metric B'; see Section 2.4 and 2.5).

In addition, the Urban and Suburban classes of the LCM2007 datasets were overlaid by AMEC in GIS with several Ordnance Survey 1:25,000 scale Vector map tiles, and cross checked against web-based aerial photography from ESRI. It was indentified that there were spatial discrepancies between the LCM2007 and the OS Vector map and aerial photography due to mapping error or land use changes since 2007. It was therefore necessary to use Ordnance Survey digital data products to improve the accuracy of the derived baseline area of focus (see Section 2.3), than simply relying on the LCM2007.

The 23 LCM2007 land classes are provided in Plate 2.4. The 25m^2 raster LCM2007 product was used within this study.

Plate 2.4 LCM2007 Land Use Classes

LCM2007 ID	Description	Comments
2700	Unclassified	Offshore sea within UK territorial waters
2701	Broadleaved, mixed and yew woodland	
2702	Coniferous woodland	
2703	Arable and horticulture	
2704	Improved grassland	
2705	Rough grassland	
2706	Neutral grassland	
2707	Calcareous grassland	
2708	Acid grassland	
2709	Fen, marsh and swamp	
2710	Heather	
2711	Heather grassland	
2712	Bog	
2713	Montane habitats	
2714	Inland rock	
2715	Saltwater	
2716	Freshwater	
2717	Supra-littoral rock	
2718	Supra-littoral sediment	
2719	Littoral rock	
2720	Littoral sediment	
2721	Saltmarsh	
2722	Urban	
2723	Suburban	

Derivation of Baseline Area of Focus

Method Description

It was necessary to exclude geographical areas from the study where carbon storage is not/will not be possible. This involved creating an ‘exclusion layer’ in GIS of such geographical areas and then using this layer to erase corresponding areas from the Natmap Carbon dataset. The exclusion layer comprises:

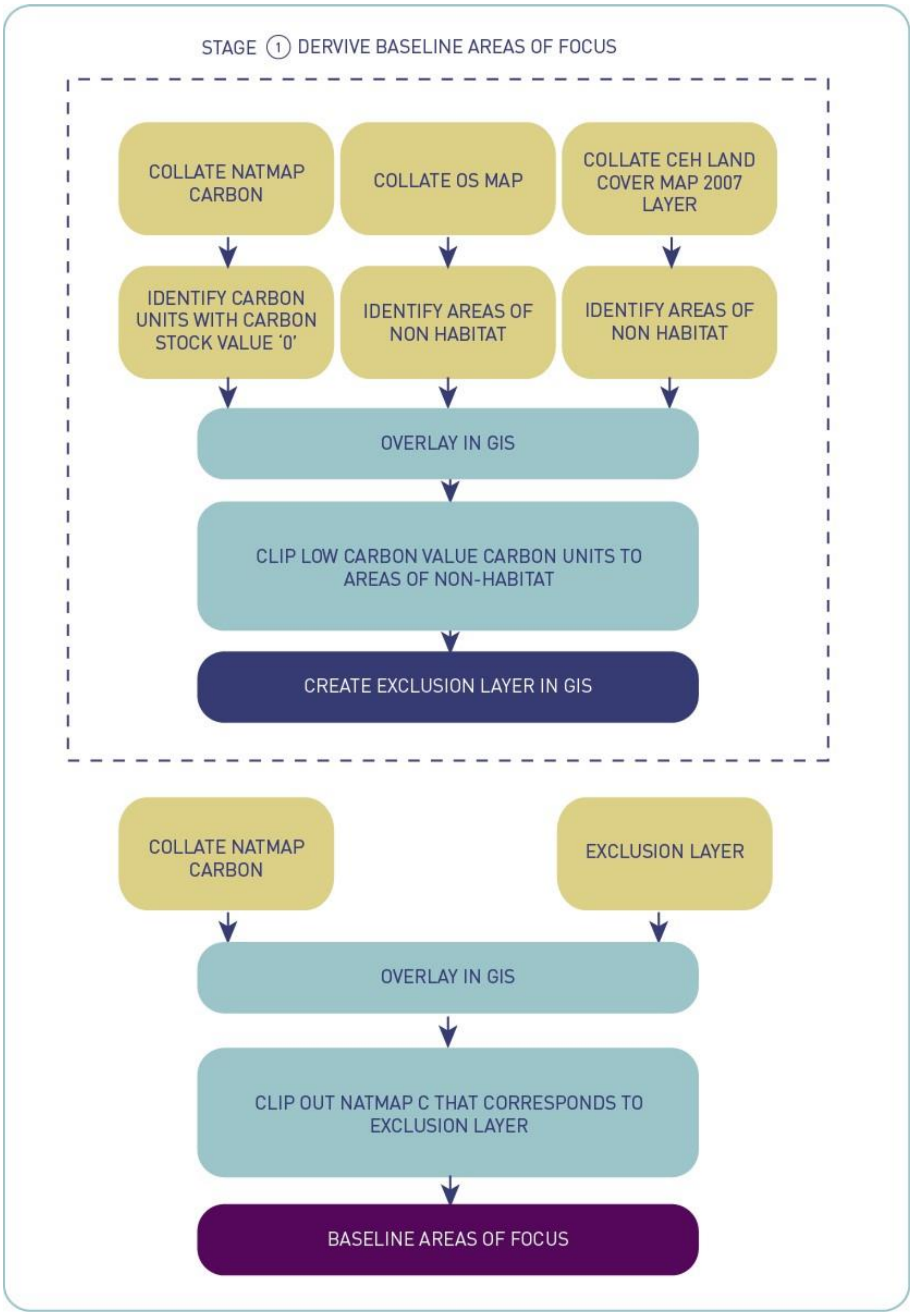
Appendix BB Carbon Units (spatial areas) within the Natmap Carbon dataset that had carbon density values of 0 Kg C/m^2 (0 t C/ha); this corresponded to fields within GIS attributes table labelled ‘AV_OC_30’, ‘AV_OC_100’, ‘AV_OC_150’;

Appendix CC Areas of ‘non-habitat’ (Urban region layer) within the Ordnance Survey Strategi dataset; and

Appendix DD Areas of ‘non-habitat’ (Urban or Sub-urban classes) within the LCM2007 land use dataset.

The process is shown in Plate 2.5.

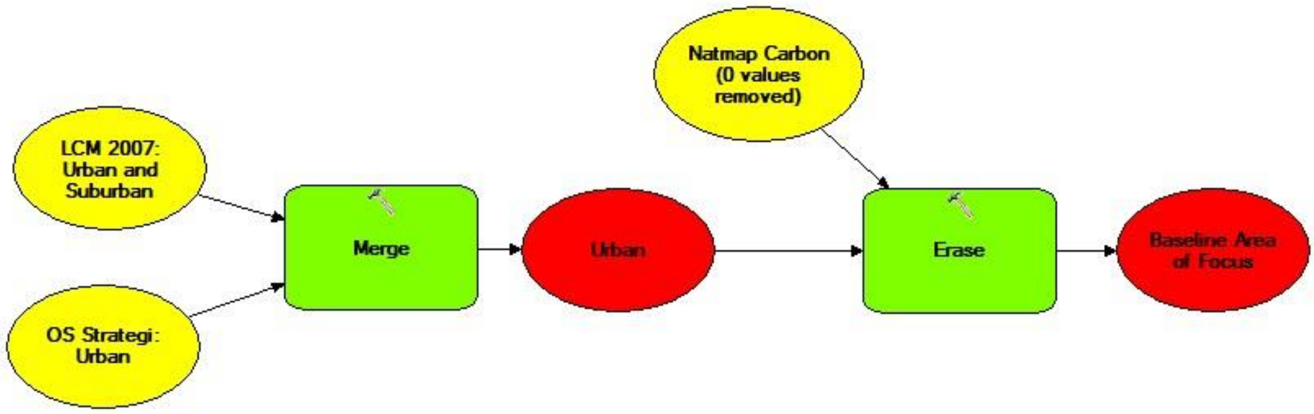
Plate 2.5 Process to Derive Baseline Area of Focus



GIS Processing

The GIS processes used to derive the Baseline Area of Focus is shown in Plate 2.6.

Plate 2.6 GIS Processing to derive the Baseline Area of Focus



Results

The Baseline Area of Focus for the study corresponding to areas where carbon is stored/could be stored is shown in Figure 2.2.

Assumptions, Clarifications and Limitations

Non-habitat was defined as Urban, Sub-urban, Open water and Sea.

Appraisal of Current Carbon Storage Performance

Method Description

Overview

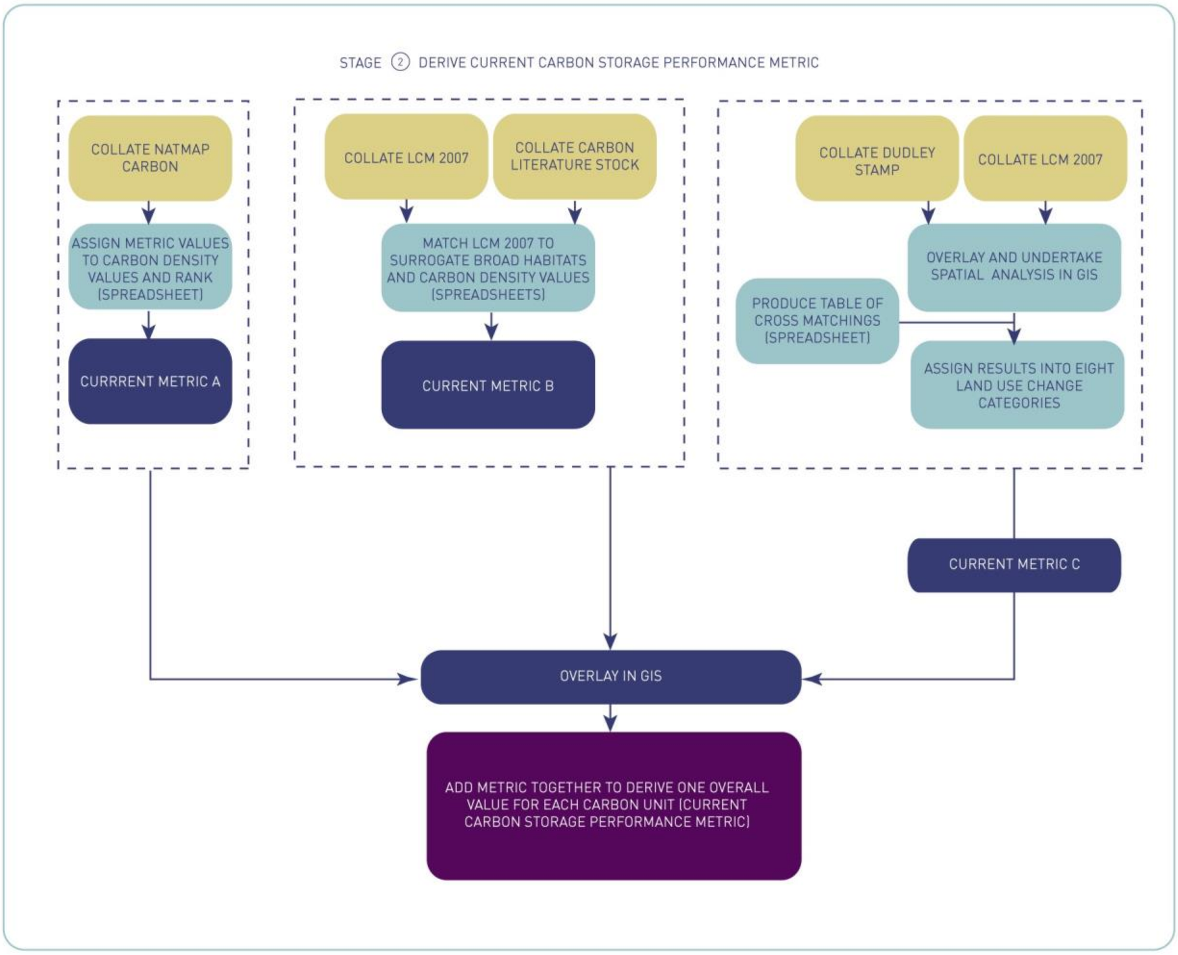
A metrics-based approach was used as a means of providing a consistent measure of prioritisation across different datasets, and to enable visual representation of the prioritisation.

The metric-based approach relied on assigning a quantitative value ('metric') to quantitative data within the different datasets. Three metrics were derived (Current Metric A (soil carbon density), Current Metric

B (carbon density by habitat/land use), Current Metric C (land use change) and these were summed to produce an overall metric entitled 'Current Carbon Storage Performance Metric'.

Current Metric A was given the highest metric values so as to weight the final overall Current Carbon Storage Performance metric towards carbon soil data, thus reducing the influence of the other metrics on the final metric score. The process is summarised in Plate 2.7 and the specific method for each metric is described below.

Plate 2.7 Process to Derive Current Carbon Storage Performance Metric



Current Metric A (soil carbon density)

The purpose of Current Metric A is to define current carbon storage based on existing soil survey data (see Section 2.2.2).

Carbon density values associated with the 'AV_OC_30', 'AV_OC_100', and 'AV_OC_150' fields within the Natmap Carbon attributes table were summed in GIS to produce a 'total average' carbon density value for the whole soil profile from 0 to 150cm below ground level for each Carbon Unit.

These total average carbon density values were then ranked and split into 11 interval categories using an automated

'Natural Breaks' function in GIS. Natural Breaks classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values. This classification is based on the Jenks' Natural Breaks algorithm of Univariate Classification Schemes (de Smith *et. al.*, 2013). For each break category the minimum and maximum carbon density values are given.

Within an excel spreadsheet, metric values ranging from 0 to 10 were then manually assigned to the 11 break categories using professional judgement and experience and based upon the automated ranking function in GIS; 0 being the lowest carbon density category (0 t C/ha) and 10 being the highest (1 155 to 1 880 t C/ha). The metric values assigned were proportionate to the range of carbon density values represented in the Natmap Carbon dataset, e.g. a metric value of 5 was assigned to the category of values ranging from 608 to 1 155 t C/ha reflecting the fact that the minimum value (608) was approximately half that of the next category (1 155 to 1 880 t C/ha).

The metric scores were then applied to a final raster called 'Current Carbon Storage Metric A' by the reclassification GIS tool. The process is indicated in Plate 2.8.

Current Metric B (carbon density by habitat/land use)

The purpose of Current Metric B is to define current carbon storage relative to habitat type/land-use, using information presented in scientific/practitioner literature.

Carbon density values were taken from relevant literature (see Section 2.2.2 describing the desk study) and matched, within an excel spreadsheet, to UK BAP Priority Habitats. UK BAP Priority Habitats were then crossmatched to the 27 land use classes of the LCM2007 dataset using professional judgement and experience. Where values in the literature were not readily attributable to UK BAP priority habitats or where values were non-existent, a 'best guess' was made.

The LCM2007 does not differentiate habitats/land use into as many categories as the UKBAP Priority Habitats list so it was necessary to aggregate carbon density values for UKBAP Priority Habitats into the broader LCM2007 categories; most notably a distinction is not made between Lowland Heathland and Upland Heathland, nor between the different types of deciduous woodland. Instead, an average of the various carbon density values was calculated and applied to the LCM2007 category (e.g. 8 different values were identified in the literature for the various deciduous woodland UK BAP Priority woodland types ranging from 130 to 208 t C/ha. These values were summed and an average of 174 t C/ha applied to the LCM 2007 category of Broadleaved, Mixed and Yew Woodland).

The carbon density values were then ranked using an automated method and metric values ranging from 0 to 4 were then manually assigned to the 11 break categories using professional judgement within an excel spreadsheet: 0 being the lowest carbon density category (0 t C / ha) for open water habitats and 4 being the highest (423 t C/ha) for upland/wetland habitats. The metric values assigned were proportionate to the range of carbon density values represented across the LCM2007 land use classes.

The metric scores were then applied to a final raster called 'Current Carbon Storage Metric B' by the reclassification GIS tool. The process is indicated in Plate 2.8.

Current Metric C (land use change)

The purpose of Current Metric C is to define change in habitat type/land-use between the 1930s and 2007.

The identification of these areas has required the spatial comparison of two datasets. These are: (a) The Land Utilisation Survey (LUS) Dudley Stamp maps (published by 1940) and (b) the Land Cover Map (LCM) 2007 dataset (see Section 2.2.3).

The derivation of this metric relied heavily on work undertaken for a previous project for Natural England (as reported in detail in Section 4 of AMEC, 2013).

The ArcGIS-Spatial Analyst geoprocessing tool was used to create a spatial dataset showing all unique combinations between the LUS Dudley Stamp and LCM2007 datasets.

The processing resulted in the creation of a GIS layer with 192 different combinations of land use change (see example in Plate 2.11 in Section 2.4.3). The combinations were then exported to an excel spreadsheet and the combinations assigned one of 8 metric values. Using this system, each of the 192 unique land use change classes were assigned to one of 8 metric values ranging from -2 (e.g. habitat lost or always lower performing habitat) to 2 (e.g. change from lower performing to higher performing habitat).

The metric scores were then applied to a final raster called 'Current Carbon Storage Metric C' by the reclassification GIS tool. The process is indicated in Plate 2.8.

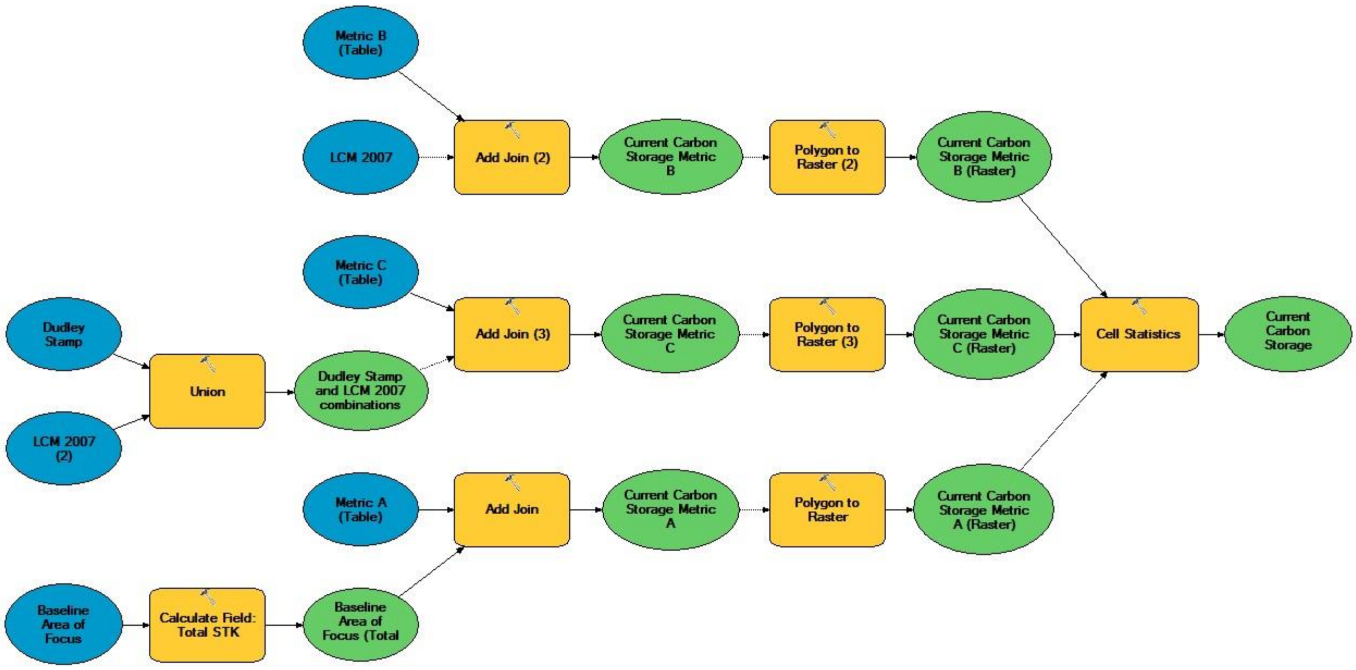
Current Carbon Storage Performance Metric

A Current Carbon Storage Performance grid was generated in GIS using the cell statistics tool and summing all the Current Metrics A_C into one 'layer', which also produced one overall metric value on a scale of -1 to 16.

GIS Processing

The GIS processes/tools used to derive Current Metrics A, B and C are shown in Plate 2.8.

Plate 2.8 GIS Processing to Derive Current Metrics A, B and C



Results

The 3 components (Metrics A-C) of the Current Carbon Storage Performance Metric are displayed below in

Plates 2.9 to 2.11 and in Appendix A. Following combination of the individual metrics, the resulting Current Carbon Storage Performance is shown in Figure 2.3; areas of lowest performance are shown in purple; areas of highest performance in red.

Plate 2.9 Current Metric A (Soil Carbon Density)

Manually Assigned Metric**	Carbon Density Range to 150cm bgl*				Comments
	Min	Max	Min	Max	
	t C/ha	t C/ha	Kg C/m2	Kg C/m2	
10	1155.4001	1879.7	115.54001	187.97	Greatest carbon density
5	607.6001	1155.4	60.76001	115.54	
4	360.9001	607.6	36.09001	60.76	
4	267.4001	360.9	26.74001	36.09	
4	211.5001	267.4	21.15001	26.74	
3	171.8001	211.5	17.18001	21.15	
3	142.6001	171.8	14.26001	17.18	
3	116.4001	142.6	11.64001	14.26	
2	81.1001	116.4	8.11001	11.64	
1	1	81.1	0.1	8.11	
0	0	0	0	0	Lowest carbon density

Table Notes:

* bgl below ground level

** Derived using professional judgement and experience and based upon the automated ranking

Plate 2.10 Current Metric B (Carbon Density by Habitat)

Manually Assigned Metric Adjusted by Values for GIS*	UK BAP Priority Habitats	UK BAP Broad Habitats	LCM 2007 Categories	Literature Values** Average Carbon		Adjusted Values for GIS*** Average Carbon Density	
				t C/ha	Kg C/m2	t C/ha	Kg C/m2
4.0 4.0	Hedgerows	Boundary and Linear Features	-	149	14.9	-	-
4.0 4.0	Upland Flushes, Fens and Swamps	Fen, Marsh and Swamp	Fen, marsh and swamp	423	42.3	423	42.3
4.0 4.0	Purple Moor Grass and Rush Pastures	Fen, Marsh and Swamp	Fen, marsh and swamp	423	42.3	423	42.3
4.0 4.0 4.0 4.0	Lowland Fens	Fen, Marsh and Swamp	Fen, marsh and swamp	423	42.3	423	42.3
4.0 4.0 3.0	Reedbeds	Fen, Marsh and Swamp	Fen, marsh and swamp	423	42.3	423	42.3
3.0	Lowland Raised Bog	Bogs	Bog	423	42.3	423	42.3
3.0	Blanket Bog	Bogs	Bog	423	42.3	423	42.3
3.0 3.0 3.0 3.0	Mountain Heaths and Willow Scrub	Montane Habitats	Montane habitats	409	40.9	409	40.9
3.0 3.0	Upland Heathland	Dwarf Shrub Heath	Heather	287.8	28.8	264	26.4
2.0	Lowland Heathland	Dwarf Shrub Heath	Heather	240.8	24.1	264	26.4
2.0 2.0	Native Pine Woodlands	Coniferous Woodland	Coniferous woodland	260.1	26.0	260.1	26.0
2.0	Lowland Dry Acid Grassland	Acid Grassland	Acid grassland	254.65	25.5	254.65	25.5
2.0	-	-	Heather Grassland	240.8	24.1	240.8	24.1
2.0	Coastal Saltmarsh	Littoral Sediment	Saltmarsh	180	18.0	180	18.0
2.0 2.0	Lowland Beech and Yew Woodland	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	h207.7	20.8	174	17.4
2.0 2.0	Wood-Pasture and Parkland	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	h 182	18.2	174	17.4

Manually Assigned Metric Adjusted by Values for GIS*	UK BAP Priority Habitats	UK BAP Broad Habitats	LCM 2007 Categories	Literature Values**		Adjusted Values for GIS***	
				Average Carbon		Average Carbon Density	
				t C/ha	Kg C/m2	t C/ha	Kg C/m2
2.0 2.0 2.0 2.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0	Traditional Orchards	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	n181.5	18.2	174	17.4
	Upland Oakwood	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	n179.4	17.9	174	17.4
	Upland Birchwoods	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	n176.1	17.6	174	17.4
	Lowland Mixed Deciduous Woodland	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	n174.9	17.5	174	17.4
	Upland Mixed Ashwoods	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	n152.1	15.2	174	17.4
	Wet Woodland	Broadleaved, Mixed and Yew Woodland	Broadleaved, mixed and yew woodla	n129.5	13.0	174	17.4
	Lowland Calcareous Grassland	Calcareous Grassland	Calcareous grassland	107	10.7	107	10.7
	Upland Calcareous Grassland	Calcareous Grassland	Calcareous grassland	107	10.7	107	10.7
	Inland Rock Outcrop and Scree Habitats	Inland Rock	Inland rock	107	10.7	107	10.7
	Calaminarian Grasslands	Inland Rock	Inland rock	107	10.7	107	10.7
	Open Mosaic Habitats on Previously Developed Land	Inland Rock	Inland rock	107	10.7	107	10.7
	Limestone Pavements	Inland Rock	Inland rock	107	10.7	107	10.7
	Maritime Cliff and Slopes	Supralittoral Rock	Supra-littoral rock	107	10.7	107	10.7
	Coastal Vegetated Shingle	Supralittoral Sediment	Supra-littoral sediment	107	10.7	107	10.7
	Machair	Supralittoral Sediment	Supra-littoral sediment	107	10.7	107	10.7

Manually Assigned Metric Adjusted by Values for GIS*	UK BAP Priority Habitats	UK BAP Broad Habitats	LCM 2007 Categories	Literature Values**		Adjusted Values for GIS***	
				Average Carbon		Average Carbon Density	
				t C/ha	Kg C/m2	t C/ha	Kg C/m2
	Coastal Sand Dunes	Supralittoral Sediment	Supra-littoral sediment	107	10.7	107	10.7
	Lowland Meadows	Neutral Grassland	Neutral grassland	106.7	10.7	106.7	10.7
	-	-	Rough grassland	106.7	10.7	106.7	10.7
	Upland Hay Meadows	Neutral Grassland	Neutral grassland	106.7	10.7	106.7	10.7
	Coastal and Floodplain Grazing Marsh	Improved Grassland	Improved grassland	106	10.6	106	10.6
	Arable Field Margins	Arable and Horticultural	Arable and horticulture	72.5	7.3	72.5	7.3
	Rivers	Rivers and Streams	Freshwater	0	0.0	0	0.0
	Oligotrophic and Dystrophic Lakes	Standing Open Water and Canals	Freshwater	0	0.0	0	0.0
	Ponds	Standing Open Water and Canals	Freshwater	0	0.0	0	0.0
	Mesotrophic Lakes	Standing Open Water and Canals	Freshwater	0	0.0	0	0.0
	Eutrophic Standing Waters	Standing Open Water and Canals	Freshwater	0	0.0	0	0.0
	Aquifer Fed Naturally Fluctuating Water Bodies	Standing Open Water and Canals	Freshwater	0	0.0	0	0.0

Table Notes:

* Derived using professional judgement and experience and based upon the automated ranking

** 'Derived values' are based upon taking the mean of individual carbon density values in the literature. Where values in the literature were not attributable to habitats, a 'best guess' was made using professional judgement and experience

Manually Assigned Metric Adjusted by Values for GIS*	UK BAP Priority Habitats	UK BAP Broad Habitats	LCM 2007 Categories	Literature Values** Average Carbon t C/ha	Literature Values** Average Carbon Kg C/m2	Adjusted Values for GIS*** Average Carbon Density t C/ha	Adjusted Values for GIS*** Average Carbon Density Kg C/m2
*** 'Adjusted Values' are where values have been aggregated according to LCM 2007 habitats because the GIS model uses LCM 2007 (e.g. Distinction between lowland heathland and upland heathland values is not made)							
Where different values existed for specific habitats within one LCM category, a mean of the individual values has been used. E.g. For 'heather' the mean was 26.4 Kg/m2 by averaging the values for lowland heathland and upland heathland							

Plate 2.11 Example of Current Metric C (land use change; upper picture) and the Rationale Behind Assigning Metric Values (lower picture)

Former Dudley Stamp (DS) Land Cover Class Present	Corresponding CEH Land Cover Class 2007 now Present	Qualitative Appraisal of Land use Change		Qualitative Appraisal of Carbon Stock Performance	Manually Assigned Metric*
Forest and Woodland	Acid grassland	Different	Positive	Remains higher performance habitat	2 2 2
Forest and Woodland	Bog	Different	Positive	Remains higher performance habitat	2
Forest and Woodland	Broadleaved, mixed and yew woodland	Same	Positive	Remains higher performance habitat	
Forest and Woodland	Calcareous grassland	Different	Positive	Remains higher performance habitat	

Former Dudley Stamp (DS) Land Cover Class Present	Corresponding CEH Land Cover Class 2007 now Present	Qualitative Appraisal of Land use Change	Qualitative Appraisal of Carbon Stock Performance	Manually Assigned Metric*

Metric		Rationale
Different +ve	2	Change from lower to a higher priority habitat/land-use
Same +ve	2	No change and remains higher priority habitat/land-use
Different +ve	1	Change from higher to lower priority habitat/land-use
Different +ve	1	Recent change from a lower to higher priority
Uncertain (neutral)	0	Uncertainty exists around apparent change (mapping error) or there is no data (unclassified)**
Same -ve	-1	No change and remains lower priority habitat/land-use that could be recovered
Different -ve	-1	Change but is still a lower priority habitat/land-use that could be recovered
Lost -ve	-2	Habitat/land-use has always been intensively managed/a lower performing habitat or has changed irrecoverably

Table Notes:

* Derived using professional judgement and experience and based upon the automated ranking

** it is not possible to determine, based upon the datasets available, whether there has been a change in land use or there is a mapping error between the two datasets due to the differences between the spatial accuracy and type of data recorded

Assumptions, Clarifications and Limitations (Current Metrics A, B and C)

The limitations of the datasets and the steps taken to account for these as described in Section 2.3.3.

Theoretically there could be 'double counting' by having two iterations of land-use weighting being applied to carbon density values, once within the Natmap Carbon dataset (Current Metric A; see also 2.2.2) and then again in Current Metric B using the LCM2007 data. However, it is considered that this potential limitation is far outweighed by the benefits of being able to derive metrics (Current Metric B and C) that more accurately reflected land cover on the ground to a finer detail (land parcels) and to take account of land cover change. See discussion in Section 2.2.2 around dataset limitations.

For Current Metric B, an element of subjectivity is introduced because a 'best guess' approach was adopted where values in the literature were not readily attributable to UK BAP priority habitats or where values were non-existent. From the literature review, it became apparent that it was not possible to establish, with any confidence, a clear and consistently comparable picture of carbon density for distinct habitats because:

Appendix EE There is simply too few sources of literature with the relevant data, and even less (1 publication) relating to land use change from one habitat to another;

Appendix FF In some cases, only broad habitats are given in the literature (e.g. grassland or wetland);

Appendix GG Values are given for tree species instead of woodland types;

Appendix HH Values quoted relate to varying soil depths (typically 15cm for non-wetland and 50cm for wetland habitats);

Appendix II For wetland habitats, the values only relate to 50cm below ground level (clearly peat resources go much deeper);

Appendix JJ Different values are quoted within the same publication for seemingly very similar land use changes;

Appendix KK Some of the values quoted for habitats include only soil or soil and vegetation, or there is no indication what it relates to;

Appendix LL Some of the values quoted for habitats include management regimes (e.g. burning) such that it is difficult to understand the value just relating to the habitat; and

Appendix MM Some of the values quoted for habitats include varying timescales (typically 1 year to 100 years).

Furthermore, dissolved organic carbon (DOC) losses from soil to the fluvial system would need to be considered to get a complete carbon balance picture but no data relating to specific habitats were identified.

There appears to be a large discrepancy (two orders of magnitude) between carbon density values for higher performing habitats (i.e. bog at 76t C/ha; see Alonso *et.al*, 2012) in the literature versus carbon density values for highest performing soils as given in Natmap Carbon (i.e.1880 t C/ha which actually relates to raised bog soils[7]; see Plate 2.9). This discrepancy may be because the literature values only relate to a soil depth of 0.5 m, whereas Natmap C values go to a depth of 1.5 m.

For Current Metric C it has been assumed that:

Appendix NN An apparent land use change from urban, suburban and water on the LUS Dudley Stamp dataset to a different habitat/land-use (e.g. water to coniferous woodland) is due to mapping errors and accordingly a metric value of 0 was assigned;

Appendix OO 'Lower performing habitats/land-use' (in terms of carbon storage) which attracted a lower metric value were deemed to be: arable and horticultural, improved grassland, inland rock, littoral rock, littoral sediment, supra-littoral rock, supra littoral sediment;

Appendix PP 'Higher performing habitats/land-use' (in terms of carbon storage) which attracted a higher metric value was deemed to be all other habitats not mentioned above;

Appendix QQ Habitats were deemed to have been lost if they were shown in the LCM2007 dataset to be either urban, suburban, freshwater or saltwater and were assigned a metric value of -2;

Appendix RR Habitats that started out in the LUS Dudley Stamp dataset as either urban suburban, or water and remained (as per the LCM 2007) lower performance habitat/land use (e.g. urban) were assigned a metric value of -2;

Appendix SS Although many water features are linear and significant errors/uncertainties are likely when comparing the LUS Dudley Stamp data with the LCM2007, the LUS Dudley Stamp data 'water' has been included because it is likely to include what is now deemed to be wetland habitats such as fen, marsh and swamp.

[7] When Soilscapes were cross matched with Natmap Carbon – see Section 3.

Note that 'Current Carbon Storage Performance' values are, or are shown as 'low' (green or yellow), around the Cambridgeshire Fens and Humber Peatlands because:

Appendix TT **Cambridgeshire Fens**: although the region has high scores against Current Metric A (Natmap Carbon), reflecting the fact that the soils in the region are suitable for carbon storage, the overall score is then downgraded by the current spatial abundance of arable/improved grassland (Current Metric B), and the historic spatial abundance of arable/improved grassland (Current Metric C);

Appendix UU **Humber Peatlands**: higher performance areas (orange) are present around the highest performing areas (e.g. Thorne and Hatfield Moors shown in red) as expected however the finer detail is lost at the map resolution (national scale at A3 size).

Appraisal of Future Carbon Storage Performance Potential

Method Description

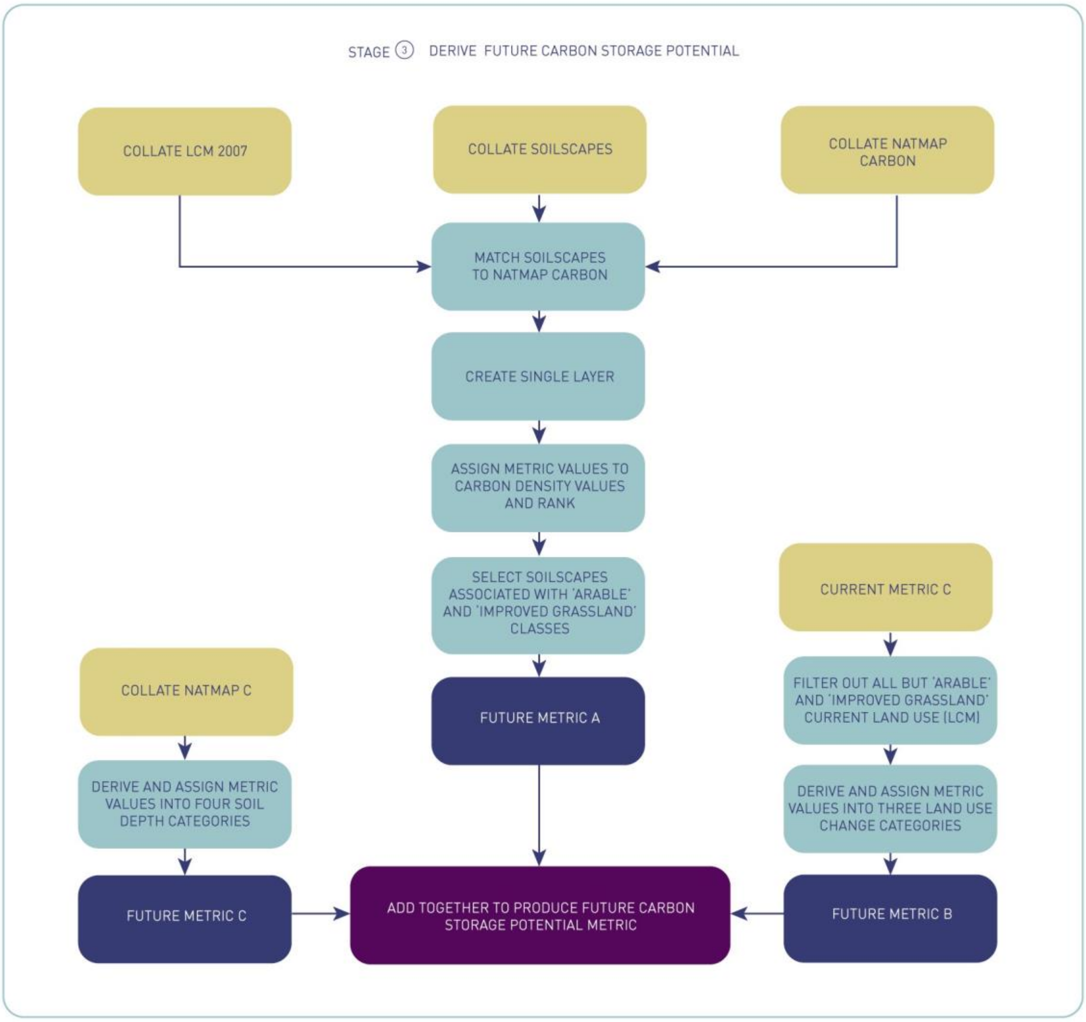
Overview

As for the Current Carbon Storage Performance Metric, a metrics-based approach was used. Three metrics were derived (Future Metric A (carbon density potential by soilscape), Future Metric B (degraded habitat metric – arable and improved grassland), Future Metric C (carbon density potential by soil depth)) and these were summed to produce an overall metric entitled Future Carbon Storage Performance Potential Metric.

Future Metric A was given the highest metric values so as to weight the final overall Future Carbon Storage Performance Potential Metric towards carbon soil data, thus reducing the influence of the other metrics on the final metric score.

The process is summarised in Plate 2.12 and the specific method for each metric is described below.

Plate 2.12 Process to Derive Future Carbon Storage Performance Potential Metric



Future Metric A (soil carbon density by specific habitats)

The purpose of Future Metric A is to define current carbon storage, with a focus on habitats/land use and soils that would be the main focus of NELMS targets/action going forward (arable and improved grassland).

The Natmap Soilscapes dataset was cross-matched with the Natmap Carbon dataset using the intersect tool in GIS and 'dissolved' to create a new 'layer'. Additionally, the output from Current metric A were selected and 'intersected/clipped' to the LCM2007 classes of 'arable' and 'improved grassland' and associated Soilscapes.

The metric scores were then applied to a final raster called 'Future Carbon Storage Metric A' by the reclassification GIS tool. The process is indicated in Plate 2.13.

Future Metric B (land use change by specific habitats)

The purpose of Future Metric B is to define change in habitat type/land-use between the 1930s and 2007, and specifically change to habitats/land use that would be the main focus of NELMS targets/action going forward (arable and improved grassland).

Therefore, the output from Current Metric C (land us change) was used and filtered in an excel spreadsheet to identify only those land use change combinations that were cross matched to the LCM 2007 classes of 'arable and horticultural' and 'improved grassland'. Metric values ranging from -1 (habitat/ land use always been intensively managed) to 1 (only recently become intensively managed) were then assigned to each land use change combination in the excel spreadsheet.

The metric scores were then applied to a final raster called 'Future Carbon Storage Metric B' by the reclassification GIS tool. The process is indicated in Plate 2.13.

Future Metric C (soil depth)

The purpose of Future Metric C is to define change in carbon storage potential relative to soil depth (on the assumption that the deeper the soil, the greater the capacity for carbon storage).

The Natmap Carbon dataset was used on the assumption that a carbon density value in one or more of the three depth categories prevailing within the Natmap Carbon dataset (0-30cm, >30-100cm, >100-150cm below ground level) meant that soil was present at that depth.

Within an excel spreadsheet, metric values ranging from 0 (soil depth uncertain) to 3 (carbon density values present at all 3 depth categories) were assigned to the three depth categories. Due to the uncertainty around whether a 0 Kg/m^2 carbon density value meant either no carbon or no soil at that depth category within the Natmap Carbon dataset, a 0 was applied. Where carbon density values were present at all three depth categories only the highest metric score was used (i.e. the metric scores were not summed across all depths).

The metric scores were then applied to a final raster called 'Future Carbon Storage Metric C' by the reclassification GIS tool. The process is indicated in Plate 2.13.

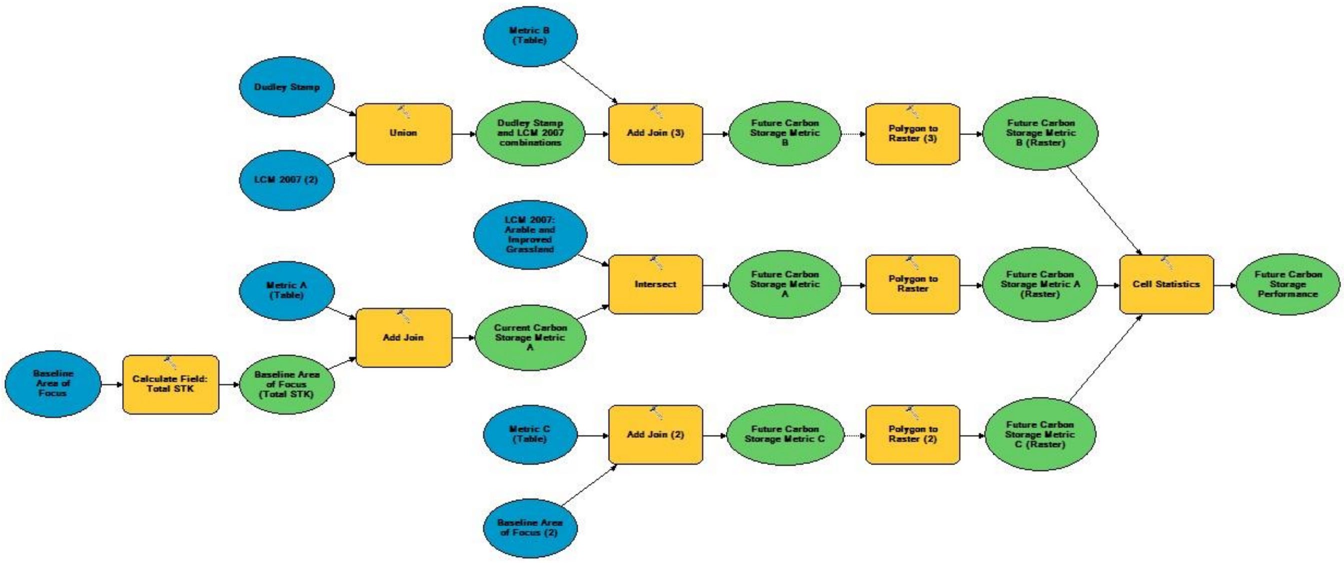
Future Carbon Storage Performance Potential

For each of two LCM2007 habitat types (Arable and Improved Grassland), a Future Carbon Storage Performance Potential grid was generated in GIS using the cell statistics tool and summing all the Future Metrics A, B and C together into one 'layer' which also produced one overall metric value on a scale of -1 to 14.

GIS Processing

The GIS processes/tools used to derive Future Metrics A, B and C are shown in Plate 2.13.

Plate 2.13 GIS Processing to Derive Future Metrics A, B and C



Results

The 3 components (Metrics A-C) of the Future Carbon Storage Performance Potential Metric are displayed below in Plates 2.14 to 2.16 and in Appendix A.

Following combination of the individual metrics, the resulting Future Carbon Storage Performance Potential is shown in Figure 2.4 and 2.5; areas of lowest potential performance are shown in purple; areas of highest potential performance in red.

Plate 2.14 Future Metric A (Carbon Density Potential by Soilscape)

Soilscape*	Average Carbon Density 0 to 150cm bgl* (NATMAP C Data) Ranked According to Soilscape (Highest to Lowest Carbon Density Values) Kg C / m2	t C / ha	Comments
Raised bog peat soils	187.97	1879.7	Greatest carbon density
Blanket bog peat soils	170.47	1704.7	
Fen peat soils	166.35	1663.5	
Shallow very acid peaty soils over rock	100.27	1002.7	
Loamy and sandy soils with naturally high groundwater and a peaty surface	79.57	795.7	
Slowly permeable wet very acid upland soils with a peaty surface	81.49	814.9	
Saltmarsh soils	32.08	320.8	
Loamy and clayey floodplain soils with naturally high groundwater	77.09	770.9	
Loamy and clayey soils of coastal flats with naturally high groundwater	46.52	465.2	
Very acid loamy upland soils with a wet peaty surface	63.11	631.1	
Freely draining floodplain soils	28.21	282.1	
Freely draining very acid sandy and loamy soils	30.82	308.2	
Freely draining acid loamy soils over rock	37.65	376.5	
Naturally wet very acid sandy and loamy soils	33.69	336.9	
Lime-rich loamy and clayey soils with impeded drainage	21.07	210.7	
Slowly permeable seasonally wet acid loamy and clayey soils	24.25	242.5	
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	24.22	242.2	
Freely draining sandy Breckland soils	15.88	158.8	
Freely draining lime-rich loamy soils	18.66	186.6	
Slightly acid loamy and clayey soils with impeded drainage	18.25	182.5	
Loamy soils with naturally high groundwater	23.44	234.4	
Freely draining slightly acid loamy soils	20.78	207.8	
Shallow lime-rich soils over chalk or limestone	31.41	314.1	
Freely draining slightly acid but base-rich soils	17.31	173.1	
Freely draining slightly acid sandy soils	17.28	172.8	
Restored soils mostly from quarry and opencast spoil	11.66	116.6	
Sand dune soils	4.7	47	Lowest carbon density

Manually Assigned Metric***	Carbon Density Range to 150cm bgl** Min t C/ha	Max t C/ha	Min Kg C/m2	Max Kg C/m2	Comments
10	1155.4	1879.7	115.54	187.97	Greatest carbon density
5	607.6001	1155.4	60.76001	115.54	
4	360.9001	607.6	36.09001	60.76	
4	267.4001	360.9	26.74001	36.09	
4	211.5001	267.4	21.15001	26.74	
3	171.8001	211.5	17.18001	21.15	
3	142.6001	171.8	14.26001	17.18	
3	116.4001	142.6	11.64001	14.26	
2	81.1001	116.4	8.11001	11.64	
1	1	81.1	0.1	8.11	
0	0	0	0	0	Lowest carbon density neisty

Table Notes:		
* LCM2007 classes arable and improved grassland are associated (to varying degrees) with all these soilscapes		
** bgl below ground level		
*** Derived using professional judgement and experience and based upon the automated ranking		

Plate 2.15 Future Metric B (Degraded Habitat Metric – Arable and Improved Grassland)

Former Dudley Stamp Land Cover Class Present	Corresponding CEH Land Cover Class 2007 now Present	Qualitative Appraisal of Land use Change		Qualitative Appraisal of Carbon Stock Performance	Manually Assigned Metric**
Forest and Woodland	Arable and horticulture	Different	Positive	Higher to lower performing habitat	1
Heath and Moorland	Arable and horticulture	Different	Positive	Higher to lower performing habitat	1
Orchard	Arable and horticulture	Different	Positive	Higher to lower performing habitat	1
Forest and Woodland	Improved grassland	Different	Positive	Higher to lower performing habitat	1
Heath and Moorland	Improved grassland	Different	Positive	Higher to lower performing habitat	1
Orchard	Improved grassland	Different	Positive	Higher to lower performing habitat	1
Meadow and Grass	Arable and horticulture	Uncertain	Neutral	Possible mapping error*	0
Suburban	Arable and horticulture	Uncertain	Neutral	Possible mapping error*	0
Urban	Arable and horticulture	Uncertain	Neutral	Possible mapping error*	0
Water	Arable and horticulture	Uncertain	Neutral	Possible mapping error*	0
Meadow and Grass	Improved grassland	Uncertain	Neutral	Possible mapping error*	0
Suburban	Improved grassland	Uncertain	Neutral	Possible mapping error*	0
Urban	Improved grassland	Uncertain	Neutral	Possible mapping error*	0
Water	Improved grassland	Uncertain	Neutral	Possible mapping error*	0
Arable	Arable and horticulture	Same	Negative	Remains lower performance habitat	-1
Arable	Improved grassland	Different	Negative	Remains lower performance habitat	-1

Former Dudley Stamp Land Cover Class Present	Corresponding CEH Land Cover Class 2007 now Present	Qualitative Appraisal of Land use Change	Qualitative Appraisal of Carbon Stock Performance	Manually Assigned Metric**

Metric	Rationale	Comments
1	Habitat/land-use has recently become arable/improved grassland from other higher performing habitat	Habitat Least Degraded
0	Mapping error/uncertainty	
-1	Habitat/land-use has always been intensivley managed	Habitat Most Degraded

Table Notes:

* it is not possible to determine, based upon the datsests available, whether there has been a change in land use or there is a mapping error between the two datassets due to the differences between the spatial accuracy and type of data recorded

** Derived using professional judgement and experience and based upon the automated ranking

Plate 2.16 Future Metric C (Carbon Density Potential by Soil Depth)

Manually Assigned Metric*	Rationale	Comments
0	Soil depth uncertain based on datsets used**	
1	A NATMAP C value is present to a depth of 30cm bgl*** or less	Shallower soil; lower carbon storage potential
2	A NATMAP C value is present to a depth of >30cm to 100cm bgl***	
3	A NATMAP C value is present to a depth of between >100cm and 150cm bgl***	Deeper soil; greater carbon storage potential

Table Notes:

* For soil depth categories >30cm only one of the above metric values is assigned, not an accumulation of the three positive metric values	
Also, metric has been derived using professional judgement and experience and based upon the automated ranking	
** a 0 NATMAP C value may indicate either that there is no carbon present and/or there is no soil to the relevant depth category, but it is nopt possible to disntguish betwene the two scenarios	
*** bgl below ground level	

Assumptions, Clarifications and Limitations (Future Metrics A, B and C)

When the LCM2007 land use classes ‘Arable and Hortiucltural’ and ‘Improved Grassland’ are cross-matched with Soilscapes, the two land use classes are associated with all Soilscapes because of the way in which the two datasets (which are at different spatial resolutions) intersect.

However, when it came to displaying the results, Arable and Horticultural and Improved Grassland are not shown all over the country, most notably in the upland areas, because all LCM2007 land use classes (and associated Soilscapes) except ‘Arable and Hortiucltural’ and ‘Improved Grassland’ were excluded during the GIS processing.

Targeted Versus Non-targeted NELMS Action

Overview

To inform decision making on land use planning, the merits of a targeted versus a non-targeted approach to land use change/action, in the context of NELMS, was investigated using a quantum of land extent (100 ha). This section describes the approach to spatial analysis of the key datasets used in the study, and the results of these analyses.

Method

The extent (Ha) of each data feature/class in the Natmap Soilscape, Natmap Carbon, and LCM2007 datasets was calculated in GIS, and collated and ranked in an excel spreadsheet, see Appendix B. The extents were then used to calculate the estimated current carbon stock values for 100 Ha of land in a targeted scenario (whereby only one or two land use classes are prioritised within NELMS, i.e. arable and improved grassland), and a non-targeted scenario (whereby there is no prioritisation in NELMS).

There are tens of possible combinations that could be chosen to demonstrate the effects of targeted versus nontargeted action. Those used for this report are more likely examples of what may happen on the ground than some that could be chosen.

The Project Workbook with more detailed calculations is provided in Appendix C.

Results

The overall results are shown in Table 3.1, and supporting detail is provided in Tables 3.2 to 3.5. However, in summary:

Appendix VV A **targeted approach** (assuming 100 Ha of one or two particular habitats are the sole focus of prioritised action) could, for example, result in:

the opportunity to prevent loss of up to 180 000 tonnes of carbon by preventing further habitat degradation of 100 Ha of wetland habitat (e.g. bog habitat) – see Table 3.1; OR

changing 100 Ha arable and/or improved grassland to a 'better performing'[8] habitat which could result in the storage of up to 3730Ha of additional tonnes of carbon every 10 years (equating to

[8] One that sequesters and stores more carbon than arable or improved grassland.

carbon stock values for 100 Ha increasing from a range an upper limit of 37 700 to 41 430 tonnes) – see Table 3.1;

Therefore, in a targeted scenario between 41,430 and 180,000 tonnes of carbon stock is secured by preventing habitat degradation OR enacting land use change to 'better performing habitat';

Appendix WW A **non-targeted approach** (assuming 100 Ha of action randomly occurring within the top seven most extensive land uses), could, for example, result in:

the opportunity to prevent loss of up to 35 328 tonnes of carbon (by preventing further habitat degradation) (assuming approximately 37 Ha[8] of habitat is prevented from degradation land is; the other 63 Ha is subject to land use change – see below) – see Table 3.1; AND

changing 63 Ha arable and/or improved grassland to a 'better performing' habitat could result in the storage of around 852 additional tonnes of carbon every 10 years (equating to carbon stock values for 63 Ha increasing from an upper limit of 19 167 to 20 948 tonnes) – see Table 3.1;

In these combined **non-targeted** scenarios, up to **56 276 tonnes** of carbon stock is secured by a combination of preventing habitat degradation and enacting land use change to 'better performing habitat' – see Table 3.1.

[8] The extent used here is based upon the proportional extent (%) these land use classes constitute to the total extent of land use in England as shown in Table 3.4 and Appendix D.

1. Table 0.1 Merits of Targeted Versus Non-targeted Scenarios Within NELMS for 100Ha of Habitat*

• Policy Decision	• Example Options	• Carbon Stock Prevented From Degradation (t C) (highest value)	• Current Carbon Stock (t C) (highest value)	• Future Carbon Stock As A Result of Land Use Change (t C) (highest value)	• Change in Carbon Stock (highest value)
Targeted (prevent degradation)	See Table 3.2 Prevent degradation of 100 Ha of bog habitat; OR:	180000	180000 (bog)	-	0
Targeted (land use change)	See Table 3.3 Change 100 Ha of agricultural land (e.g. all improved grassland) to 'better performing' (non-wetland) habitat (e.g. woodland)	-	37700 (improved grassland)	41430	+3730
Carbon Secured (Targeted) Sub-total			**41430 OR 180000**		
Non-targeted (randomised action) (prevent degradation)	See Table 3.4 Prevent degradation of 37 Ha of various semi-natural habitats (top seven most extensive habitats); AND:	35328	-	-	0
Non-targeted (randomised action) (land use change)	See Table 3.5 Change 63 Ha of agricultural land (arable or improved grassland) to	-	19167	20948	+1781

• Policy Decision	• Example Options	• Carbon Stock Prevented From Degradation (t C) (highest value)	• Current Carbon Stock (t C) (highest value)	• Future Carbon Stock As A Result of Land Use Change (t C) (highest value)	• Change in Carbon Stock (highest value)
	'better performing' (non-wetland) habitat (e.g. woodland)				
Carbon Secured (Non-targeted) Sub-total			**56276**		

* Highest values are taken from Tables 3.2 and 3.3.

2. Table 0.2 stimated Current Carbon Stock Values for 100Ha (Targeted Scenario)

• LCM2007 Land Use Class	• Associated Soilscapes*	• Carbon Density (t C/ha) (Natmap C Soils Matched to Soilscapes)**	• Current Carbon Stock (t C) Range for 100 Ha (Soils)***	• Policy Decision
Bog	**Most extensive**: Blanket bog soils	1800	**33000 – 180000**	**Prevent further degradation**
Bog	**Less extensive**: Naturally wet very acid sandy and loamy soils	337		
Arable and horticultural	**Most extensive**: Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	242	**18700 – 24200**	**Change land use to capture more carbon**
Arable and horticultural	**Less extensive**: Freely draining lime-rich loamy soils	187		
Improved grassland	**Less extensive**: Freely draining acid loamy soils over rock	377	**20800 – 37700**	**Change land use to capture more carbon**
Improved grassland	**Most extensive**: Freely draining slightly acid loamy soils	208		

*'Less Extensive' Soilscapes are those that are at or just above 5% of the total extent of Soilscapes for the given land use class. ** Carbon Density values are for the 'most extensive' and 'less extensive' Soilscapes associated with the LCM 2007 habitats shown.
***Carbon Stock = 100Ha x Carbon Density. A range is given because different Soilscapes have different Carbon Density values.

3. Table 0.3 Predicted Future Carbon Stock Values for 100Ha (Targeted Scenario) Due to Land Use Change

• LCM2007 Land Use Class Change	• Additional Carbon Sequestered (t C02e- /Ha/yr)*	• Additional Carbon Density (t C/Ha /yr)**	• Additional Carbon Sequestered Over 10 Years (t C/Ha)	• Additional Carbon Stored (t C) Over 10 Years for 100Ha ('Column A')	• Current Carbon Stock (t C) Range for 100 Ha ('Column B')	• Predicted Future Carbon Stock (t C) Range for 100 Ha***
Arable to forestry	7.52[a]	2.05	20.5	2050	18700 – 24200	**20750 – 26250**
Improved grassland to woodland	13.7[b]	3.73	37.3	3730	20800 – 37700	**24530 – 41430**

* Based upon values given in Alonso *et. al* (2012).
** t C/Ha/yr = t C02e- /Ha/yr divided by 3.67 (Natural England, 2012).
*** Based upon the range of Carbon Density values given in 'Column B' plus 'Column A'. A range is given because different Soilscapes have different Carbon Density values. [a] Value achieved after 115 years. [b] Value achieved between years 2 and 20 and includes soils and vegetation.

4. Table 0.4 Estimated Current Carbon Stock Values for 100Ha (Non-Targeted Scenario)*

• LCM2007 Land Use Class	• Extent (Ha) Expressed Proportionally Across 100Ha** ('Column A')	• Associated Natmap Soilscapes***	• Carbon Density (t C/ha) (Natmap C) ('Column B')	• Current Carbon Stock (t C) Range for 100 Ha****	• Policy Decision
Arable and horticulture	33.2	**Most extensive**: Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils **Less extensive**: Freely draining lime-rich loamy soils	242 187	**6209 - 8035**	**Change land use (capture more carbon)**

• LCM2007 Land Use Class	• Extent (Ha) Expressed Proportionally Across 100Ha** ('Column A')	• Associated Natmap Soilscapes***	• Carbon Density (t C/ha) (Natmap C) ('Column B')	• Current Carbon Stock (t C) Range for 100 Ha****	• Policy Decision
Improved grassland	29.5	**Most extensive**: Freely draining slightly acid loamy soils **Less extensive**: Freely draining acid loamy soils over rock	208 377	**6142 - 11132**	**Change land use (capture more carbon)**
Sub-total	**62.7**	**-**	**-**	**12351 - 19167**	**-**
Acid grassland	8.7	**Most extensive**: Very acid loamy upland soils with a wet peaty surface **Less extensive**: Shallow very acid peaty soils over rock	631 1003	**5481 - 8713**	**Prevent further degradation**
Coniferous woodland	7.7	**Most extensive**: Freely draining acid loamy soils over rock **Less extensive**: Blanket bog peat soils	377 1705	**2901 - 13121**	**Prevent further degradation**
Broadleaved, mixed and yew woodland	7.0	**Most extensive**: Freely draining slightly acid loamy soils **Less extensive**: Shallow lime-rich soils over chalk or limestone	208 314	**1466 - 2213**	**Prevent further degradation**
Heather grassland	7.0	**Most extensive**: Slowly permeable wet very acid upland soils with a peaty surface **Less extensive**: Slowly permeable seasonally wet acid loamy and clayey soils	815 243	**1696 - 5689**	**Prevent further degradation**
Rough grassland	6.9	**Most extensive**: Freely draining slightly acid loamy soils	208	**1427 - 5592**	**Prevent further degradation**

• LCM2007 Land Use Class	• Extent (Ha) Expressed Proportionally Across 100Ha** ('Column A')	• Associated Natmap Soilscapes***	• Carbon Density (t C/ha) (Natmap C) ('Column B')	• Current Carbon Stock (t C) Range for 100 Ha****	• Policy Decision
		Less extensive: Slowly permeable wet very acid upland soils with a peaty surface	815		
Sub-total	**37.3**	**-**	**-**	**12971 – 35328**	
TOTALS	**100**	**-**	**-**	**25322 – 54495**	

*It is assumed a non-targeted (random) approach would include land from each of the top seven most extensive land uses and associated Soilscapes.
** Extent is expressed proportionally based upon the % these land use classes constitute to the total extent of land use in England.
***'Less Extensive' Soilscapes are those that are at or just above 5% of the total extent of Soilscapes for the given land use class.
**** Carbon Stock = Proportional Extent (Ha) ('Column A') x Carbon Density ('Column B').

5. Table 0.5 Predicted Future Carbon Stock Values for 62.7Ha (Non-Targeted Scenario) Due to Land Use Change*

• LCM2007 Land Use Class Change	• Additional Carbon Sequestered (t C02e- /Ha/yr)**	• Additional Carbon Density (t C/Ha /yr)***	• Additional Carbon Sequestered Over 10 Years (t C/Ha)	• Additional Carbon Stored (t C) Over 10 Years for 62.7Ha (t C) ('Column A')	• Current Carbon Stock (t C) Range for 62.7Ha • ('Column B')	• Predicted Future Carbon Stock (t C) Range for 62.7 Ha****
Arable to forestry	7.52[a]	2.05	20.5	681 (for 33.2 Ha)	6209 - 8035	**6890 – 8716**
Improved grassland to woodland	13.7[b]	3.73	37.3	1100 (for 29.5 Ha)	6142 - 11132	**7242 – 12232**
TOTALS	**-**	**-**	**-**	1781 (for 62.7 Ha)	12351 - 19167	**14132 – 20948**

* It is assumed the other 37.3 Ha is not subject to land use change.
**Based upon values given in Alonso *et. al* (2012).
*** t C/Ha/yr = t C02e- /Ha/yr divided by 3.67 (Natural England, 2012).
**** Based upon the range of Carbon Density values given in 'Column B', plus 'Column A'. A range is given because different Soilscapes have different Carbon Density values. [a] Value achieved after 115 years. [b] Value achieved between years 2 and 20 and includes soils and vegetation.

Assumption, Clarifications and Limitations

It was assumed that a non-targeted (random) approach would in all probability take in the top seven most extensive land uses and associated Soilscapes as described in Table 3.4. The extent of these top seven most extensive land use classes is expressed proportionally based upon the distribution (%) these land use classes constitute to the total extent of land use in England.

There appears to be a large discrepancy (two orders of magnitude) between carbon density values for highest performing soils as given in Natmap Carbon (i.e. 1 880 t C/ha which relates to raised bog soils; see Appendix B) and higher performing habitats (i.e. bog at 76t C/ha; see Alonso *et.al*, 2012 in Appendix D) in the literature. This discrepancy may be because the literature values only relate to a soil depth of 0.5 m, whereas Natmap C values go to a depth of 1.5m, taking in more carbon resource at depth.

The calculations undertaken are subjective, based upon many assumptions and involve data discrepancies as described above and earlier in the report. For example, it is not clear why 'arable to forestry' over 115 years sequesters less carbon per hectare than 'improved grassland to woodland' over 20 years' (see Table 3.5). In addition, only one literature source was located that provided data on carbon sequestration due to land use changes for certain habitats/land uses (Alonso *et.al*, 2012). There is therefore limited confidence in scaling up 'additional carbon sequestered' values per hectare to 'predicted future carbon stock values' for large geographical areas due to habitat changes, and the calculations and results are to be treated with caution.

Conclusions and Suggestions

Implications for Land Use Planning in NELMS

For land use decision making, it is clear that there is a trade-off to be made between targeting those habitats/soil types which may be extensive but have limited carbon density values and targeting those habitats/soil types which have high carbon density values but are limited in extent. This has important implications for decision making.

Based upon the example scenarios, and in order to maximise carbon storage per quantum of land available for action under NELMS (e.g. 100 Ha), it is recommended that either:

Appendix XX There is a targeted approach towards securing existing carbon resources associated with highest performing habitats (e.g. bog), by preventing further habitat degradation[9]; **OR**

Appendix YY a 'mixed' targeted approach is adopted, whereby:

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[9] However, there are other drivers for this – see Wetland Vision at http://www.wetlandvision.org.uk/

further degradation of existing semi-natural habitats with good carbon storage is prevented; whilst

ALSO

ensuring that existing agricultural land uses are changed to semi-natural habitats.

However, given that the extent of land under arable or improved grassland in England constitutes 1 173 875 Ha (50% of all land use) (see Plate B.2 in Appendix B), clearly there is a great opportunity to deliver significant carbon storage benefits.

Carbon Balance Consequences of Land Use Change

It was apparent from the literature review that it was not possible to establish, with any confidence, a clear and consistently comparable picture of carbon density and carbon balance (GHG/carbon emissions/sequestration) for distinct habitats because:

Appendix ZZ There is simply too few sources of literature with the relevant data, and even less (1 publication) relating to land use change from one habitat to another;

Appendix AAA Only broad habitats are given in the literature (e.g. grassland or wetland);

Appendix BBB Values quoted relate to varying soil depths (typically 15cm for non-wetland and 50cm for wetland habitats);

Appendix CCC For wetland habitats, the values only relate to 50cm below ground level (clearly peat resources go much deeper);

Appendix DDD Different values are quoted within the same publication for seemingly very similar land use changes;

Appendix EEE Some of the values quoted for habitats include only soil or soil and vegetation, or there is no indication what it relates to (e.g. see footnotes to Table 4.1);

Appendix FFF Some of the values quoted for habitats include management regimes (e.g. burning) such that it is difficult to understand the value just relating to the habitat;

Appendix GGG Some of the values quoted for habitats include varying timescales (typically 1 year to 100 years) (e.g. see footnotes to Table 4.1);

Appendix HHH Some values seem to make little sense; e.g. removing trees from heath results in GHG emission whilst maintenance of semi-natural lowland fen results in GHG emission (see Table 4.1); and,

Appendix III The carbon density values for higher performing habitats (i.e. bog) in the literature (taking into account soil and vegetation) are two orders of magnitude lower than carbon density values for highest performing soils (raised bog soils) when cross matching the Natmap Soilscapes with Natmap Carbon values.

Furthermore, dissolved organic carbon (DOC) losses from soil to the fluvial system would need to be considered to get a complete carbon balance picture, but no data relating to specific habitats were identified during the desk study.

Table 4.1 highlights some of the carbon balance consequences of various land management options (Alonso *et.al*., 2012).

6. Table 4.1 Carbon Balance Consequences of Land Management Options*

• LCM2007 Land Use Class Change	• Carbon Balance (t C02e- /Ha/yr) ('Column A')	• Change in Carbon Density (t C/Ha/yr)**	• Additional Carbon Sequestered/Emitted Over 10 Years (t C/Ha)
Arable to improved/neutral grassland	-1.10 to -2.93[a]	-0.30 to -0.80	-3.0 to -8.0
Arable to forestry	-7.52[b]	-2.05	-20.5
Arable to wetland	-8.07 to -16.87	-2.2 to -4.6	-22.0 to -46.0
Arable to heath	-4.13[c]	-1.13	-11.3
Improved grassland to woodland	-7.83 to -13.7[d]	-2.13 to -3.73	-21.3 to -37.3
(Improved) grassland to wetland	-2.39 to -14.30	-0.65 to -3.90	-65.0 to -39.0
(Trees) woodland to heath	+4.46	+1.22	+12.2
(Maintenance of) semi-natural lowland fen	+4.2	+1.14	+11.4
(Maintenance of) semi-natural raised bog	-4.11	-1.12	-11.2

*Based upon values given in Alonso *et. al* (2012); - indicates carbon captured (sequestered); + indicates carbon emitted.

** Assumes all the carbon balance values in Column A are for $C0_2$; t C/Ha/yr = t C02e- /Ha/yr divided by 3.67 (Natural England, 2012). [a] Value achieved after 50 years. [b] Value achieved after 115 years and includes soil and vegetation. [c] Value is the net value taking into +7.45 in year 1 (vegetation) and -3.32 in years 1 to 100 (soil). [d] First value is achieved at year 1 and includes soil and vegetation; second value is achieved between years 2 and 20 and includes soils and vegetation.

Worrall *et.al*. (2011) expands on the issue of limited confidence in reliably using carbon sequestration/emission values for land use change:

> ‘’Throughout this review it has become apparent that there has been very little work on the C and GHG flux for some categories of land management or peatland types. Furthermore, research reviewed was often conducted using different experimental and monitoring techniques, which has complicated direct comparisons or up-scaling to a national level. This has implications for the scale of the research required to generate emissions factors that relate to a broad range of environmental conditions and may limit the applicability of potential emissions factors generated at an early stage’’.

An explanation for why some habitat types seemingly emit GHG following restoration is provided in Natural England (2010) as follows:

> “...peat restoration generally decreases emissions of CO_2, may increase or decrease nitrous oxide emissions, and generally increases methane emissions. In some cases, restoration may result in overall increases of greenhouse gas emissions. However, these higher emissions are usually seen as a temporary phase which is followed by greenhouse gas flux more akin to that of an undamaged peatland...
>
> ...A number of recent literature reviews have all concluded that restored peatlands generally have less of an impact on global warming than degraded peatlands. Thus, restoration is generally beneficial from a global warming point of view. However, there is a clear requirement for more research into greenhouse gas and carbon flux from peatlands under existing and restoration management...
>
> Restoration of afforested peatlands may be seen as resulting in an immediate loss of the carbon stored in the trees...Following felling the restored bog vegetation would sequester carbon more slowly than the trees, meaning that initially, the restoration would be unlikely to deliver overall greenhouse gas benefits. However, the loss of carbon from the peat would be slowed, and, if successful, restoration would deliver new long-term carbon sequestration. After ~150 years or more peatland restoration would probably begin to deliver more greenhouse gas benefits than afforestation. This calculation is based on only consideration of gaseous emissions, and conservatively only considers CO_2 emissions from afforested peatlands. Including methane emissions from afforested peat, and emissions from dissolved and particulate carbon being lost from afforested peatlands would be likely to result in earlier emissions benefits being realised...’’

Clearly, further research on the carbon balance consequences of restoring wetlands (peatlands) is still needed and the timescales for realising GHG benefits from restoring wetlands could be hundreds of years (Natural England, 2010; JNCC, 2011). AMEC’s analysis of the datasets used in this study shows that although Soilscapes beneath mire (peatland) habitats[10] are the highest performing in terms of carbon density, these Soilscapes only account for <3.5% (388 192 Ha) of the total extent (area) of the UK (see Appendix B). Taking into account carbon density in vegetation AND in soils by habitat type, coniferous and deciduous woodland holds the greatest carbon density of any habitat per hectare, compared to, for example, fen and bog (Appendix D, Alonso *et.al*, 2012).

In this context, conversion of arable or improved grassland to woodland seems to be the most pragmatic solution for increasing carbon storage via an agri-environment action. Calculations by AMEC for this study suggest that conversion of arable or improved grassland to woodland/forestry could result in the capture of up to an additional 3.73 t C/ha, which equates to 3 730 tonnes of carbon for every 100 ha over 10 years (see Section 3.3). Assuming only 1% (11 739 Ha) of available agricultural land currently under arable and/or improved grassland is given over to woodland/forestry, then that equates to an increase in carbon density (storage) of up to 437 864 tonnes of carbon over 10 years.

Suggestions

In the above context, and based upon the analysis presented in this report, it is recommended that conversion of arable or improved grassland to woodland seems to be the most pragmatic solution for increasing carbon storage over short to medium timescales, augmenting work that is being done across the country under different policies and drivers to restore/create wetlands (peatlands)[11] for realising benefits over longer timescales.

It is also recommended that further research or rationalisation of existing values and value discrepancies between datasets/literature by sector experts is needed for the carbon balance consequences of changing from one specific habitat to another because currently the values are contradictory and not comparable.

For further research, maintaining the same set of parameters (consistent soil depth, management, timescales, vegetation plus soil) to allow direct comparisons to be made with confidence is recommended. The results could be used to refine the analysis work undertaken in this study.

[10] Raised bog soils, blanket bog soils, fen peat soils.

[11] See Wetland Vision at http://www.wetlandvision.org.uk/

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Figures

Project Workbook (Current and Future Carbon Storage Performance Metrics)

Spatial Calculations

• **Plate B.1 Spatial Extent of Individual Natmap Soilscapes**

SOILSCAPE	Area (Km^2) England	Area (Ha) England	As a % of total	Comment
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	21887	2188656	19.61%	Most extensive
Freely draining slightly acid loamy soils	16986	1698640	15.22%	
Slightly acid loamy and clayey soils with impeded drainage	11930	1193023	10.69%	
Shallow lime-rich soils over chalk or limestone	8358	835800	7.49%	
Slowly permeable seasonally wet acid loamy and clayey soils	7383	738266	6.62%	
Lime-rich loamy and clayey soils with impeded drainage	6157	615694	5.52%	
Loamy and clayey soils of coastal flats with naturally high groundwater	4219	421855	3.78%	
Freely draining lime-rich loamy soils	4110	410961	3.68%	
Slowly permeable wet very acid upland soils with a peaty surface	3799	379916	3.40%	
Freely draining slightly acid but base-rich soils	3267	326738	2.93%	
Freely draining acid loamy soils over rock	3174	317403	2.84%	
Freely draining slightly acid sandy soils	2959	295911	2.65%	
Loamy and clayey floodplain soils with naturally high groundwater	2837	283747	2.54%	
Blanket bog peat soils	2667	266654	2.39%	
Very acid loamy upland soils with a wet peaty surface	1997	199683	1.79%	
Loamy and sandy soils with naturally high groundwater and a peaty surface	1883	188296	1.69%	
Naturally wet very acid sandy and loamy soils	1871	187110	1.68%	
Loamy soils with naturally high groundwater	1507	150664	1.35%	
Freely draining very acid sandy and loamy soils	1114	111439	1.00%	
Fen peat soils	846	84560	0.76%	
Freely draining floodplain soils	656	65627	0.59%	
Shallow very acid peaty soils over rock	494	49402	0.44%	
Restored soils mostly from quarry and opencast spoil	425	42460	0.38%	
Freely draining sandy Breckland soils	406	40617	0.36%	
Raised bog peat soils	370	36979	0.33%	
Saltmarsh soils	195	19491	0.17%	
Sand dune soils	104	10437	0.09%	Least extensive

Plate B.2 Spatial Extent of Individual LCM2007 Land Use Classes

LCM 2007	Area (Km^2) England	Area (Ha) England	As a % of total	Comment
Arable and horticulture	6213158	621316	26.54%	Most extensive
Improved grassland	5525587	552559	23.60%	
Acid grassland	1625523	162552	6.94%	
Coniferous woodland	1440050	144005	6.15%	
Broadleaved, mixed and yew woodland	1318658	131866	5.63%	
Heather grassland	1306177	130618	5.58%	
Rough grassland	1284092	128409	5.48%	
Suburban	1088313	108831	4.65%	
Bog	1006761	100676	4.30%	
Heather	732877	73288	3.13%	
Montane habitats	491045	49105	2.10%	
Urban	312017	31202	1.33%	
Freshwater	261550	26155	1.12%	
Littoral sediment	208049	20805	0.89%	
Saltwater	153874	15387	0.66%	
Neutral grassland	128994	12899	0.55%	
Inland rock	121632	12163	0.52%	
Littoral rock	49217	4922	0.21%	
Supra-littoral sediment	46614	4661	0.20%	
Saltmarsh	44158	4416	0.19%	
Calcareous grassland	37053	3705	0.16%	
Fen, marsh and swamp	9985	998	0.04%	
Supra-littoral rock	7821	782	0.03%	Least extensive

Plate B.3 Spatial Extent of Individual Natmap Soilscapes Matched to Natmap Carbon Values

Soilscape*	Average Carbon Density 0 to 150cm bgl* (NATMAP C Data) Ranked According to Soilscape (Highest to Lowest Carbon Density Values)		Comments	Spatial Analysis		
	Kg C / m2	t C / ha		Area (Km^2) England	Area (Ha) England	As a % of Total
Raised bog peat soils	187.97	1879.7	Greatest carbon density	370	36979	0.33%
Blanket bog peat soils	170.47	1704.7		2667	266654	2.39%
Fen peat soils	166.35	1663.5		846	84560	0.76%
Shallow very acid peaty soils over rock	100.27	1002.7		494	49402	0.44%
Loamy and sandy soils with naturally high groundwater and a peaty surface	79.57	795.7		1883	188296	1.69%
Slowly permeable wet very acid upland soils with a peaty surface	81.49	814.9		3799	379916	3.40%
Saltmarsh soils	32.08	320.8		195	19491	0.17%
Loamy and clayey floodplain soils with naturally high groundwater	77.09	770.9		2837	283747	2.54%
Loamy and clayey soils of coastal flats with naturally high groundwater	46.52	465.2		4219	421855	3.78%
Very acid loamy upland soils with a wet peaty surface	63.11	631.1		1997	199683	1.79%
Freely draining floodplain soils	28.21	282.1		656	65627	0.59%
Freely draining very acid sandy and loamy soils	30.82	308.2		1114	111439	1.00%
Freely draining acid loamy soils over rock	37.65	376.5		3174	317403	2.84%
Naturally wet very acid sandy and loamy soils	33.69	336.9		1871	187110	1.68%
Lime-rich loamy and clayey soils with impeded drainage	21.07	210.7		6157	615694	5.52%
Slowly permeable seasonally wet acid loamy and clayey soils	24.25	242.5		7383	738266	6.62%
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	24.22	242.2		21887	2188656	19.61%
Freely draining sandy Breckland soils	15.88	158.8		406	40617	0.36%
Freely draining lime-rich loamy soils	18.66	186.6		4110	410961	3.68%
Slightly acid loamy and clayey soils with impeded drainage	18.25	182.5		11930	1193023	10.69%
Loamy soils with naturally high groundwater	23.44	234.4		1507	150664	1.35%
Freely draining slightly acid loamy soils	20.78	207.8		16986	1698640	15.22%
Shallow lime-rich soils over chalk or limestone	31.41	314.1		8358	835800	7.49%
Freely draining slightly acid but base-rich soils	17.31	173.1		3267	326738	2.93%
Freely draining slightly acid sandy soils	17.28	172.8		2959	295911	2.65%
Restored soils mostly from quarry and opencast spoil	11.66	116.6		425	42460	0.38%
Sand dune soils	4.7	47	Lowest carbon density	104	10437	0.09%

Plate B.4 Spatial Extent of Individual Natmap Soilscapes Matched to Arable (LCM2007)

LCM2007	Soilscape	Area (Km^2) England	Area (Ha) England	As a % of total for that land use
Arable and horticulture	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	1145401	11454	20.81%
Arable and horticulture	Freely draining slightly acid loamy soils	847935	8479	15.40%
Arable and horticulture	Slightly acid loamy and clayey soils with impeded drainage	660943	6609	12.01%
Arable and horticulture	Shallow lime-rich soils over chalk or limestone	501375	5014	9.11%
Arable and horticulture	Lime-rich loamy and clayey soils with impeded drainage	450711	4507	8.19%
Arable and horticulture	Loamy and clayey soils of coastal flats with naturally high groundwater	331810	3318	6.03%

LCM2007	Soilscape	Area (Km^2) England	Area (Ha) England	As a % of total for that land use
Arable and horticulture	Freely draining lime-rich loamy soils	315321	3153	5.73%
Arable and horticulture	Slowly permeable seasonally wet acid loamy and clayey soils	229021	2290	4.16%
Arable and horticulture	Freely draining slightly acid but base-rich soils	169239	1692	3.07%
Arable and horticulture	Freely draining slightly acid sandy soils	164840	1648	2.99%
Arable and horticulture	Loamy and clayey floodplain soils with naturally high groundwater	134095	1341	2.44%
Arable and horticulture	Loamy and sandy soils with naturally high groundwater and a peaty surface	131013	1310	2.38%
Arable and horticulture	Naturally wet very acid sandy and loamy soils	96930	969	1.76%
Arable and horticulture	Loamy soils with naturally high groundwater	82788	828	1.50%
Arable and horticulture	Freely draining acid loamy soils over rock	80188	802	1.46%
Arable and horticulture	Fen peat soils	40328	403	0.73%
Arable and horticulture	Freely draining floodplain soils	33565	336	0.61%
Arable and horticulture	Restored soils mostly from quarry and opencast spoil	22271	223	0.40%
Arable and horticulture	Freely draining sandy Breckland soils	19239	192	0.35%
Arable and horticulture	Freely draining very acid sandy and loamy soils	16902	169	0.31%
Arable and horticulture	Slowly permeable wet very acid upland soils with a peaty surface	9694	97	0.18%
Arable and horticulture	Raised bog peat soils	9285	93	0.17%
Arable and horticulture	Very acid loamy upland soils with a wet peaty surface	9020	90	0.16%
Arable and horticulture	Sand dune soils	1260	13	0.02%
Arable and horticulture	Saltmarsh soils	953	10	0.02%

LCM2007	Soilscape	Area (Km^2) England	Area (Ha) England	As a % of total for that land use
Arable and horticulture	Blanket bog peat soils	702	7	0.01%
Arable and horticulture	Shallow very acid peaty soils over rock	183	2	0.00%

Plate B.5 Spatial Extent of Individual Natmap Soilscapes Matched to Improved Grassland (LCM2007)

LCM2007	Soilscape	Area (Km^2) England	Area (Ha) England	As a % of total for that land use
Improved grassland	Freely draining slightly acid loamy soils	967294	9673	21.95%
Improved grassland	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	835048	8350	18.94%
Improved grassland	Slowly permeable seasonally wet acid loamy and clayey soils	571475	5715	12.97%
Improved grassland	Slightly acid loamy and clayey soils with impeded drainage	422121	4221	9.58%
Improved grassland	Freely draining acid loamy soils over rock	305304	3053	6.93%
Improved grassland	Shallow lime-rich soils over chalk or limestone	195515	1955	4.44%
Improved grassland	Freely draining slightly acid but base-rich soils	159235	1592	3.61%
Improved grassland	Loamy and clayey floodplain soils with naturally high groundwater	141752	1418	3.22%
Improved grassland	Lime-rich loamy and clayey soils with impeded drainage	134657	1347	3.05%
Improved grassland	Slowly permeable wet very acid upland soils with a peaty surface	96629	966	2.19%
Improved grassland	Loamy and clayey soils of coastal flats with naturally high groundwater	89301	893	2.03%
Improved grassland	Freely draining slightly acid sandy soils	86087	861	1.95%
Improved grassland	Freely draining lime-rich loamy soils	83826	838	1.90%

LCM2007	Soilscape	Area (Km^2) England	Area (Ha) England	As a % of total for that land use
Improved grassland	Loamy soils with naturally high groundwater	56775	568	1.29%
Improved grassland	Very acid loamy upland soils with a wet peaty surface	47221	472	1.07%
Improved grassland	Freely draining floodplain soils	47053	471	1.07%
Improved grassland	Naturally wet very acid sandy and loamy soils	40530	405	0.92%
Improved grassland	Loamy and sandy soils with naturally high groundwater and a peaty surface	37660	377	0.85%
Improved grassland	Fen peat soils	29257	293	0.66%
Improved grassland	Freely draining very acid sandy and loamy soils	22113	221	0.50%
Improved grassland	Restored soils mostly from quarry and opencast spoil	19591	196	0.44%
Improved grassland	Sand dune soils	4718	47	0.11%
Improved grassland	Raised bog peat soils	4613	46	0.10%
Improved grassland	Freely draining sandy Breckland soils	4310	43	0.10%
Improved grassland	Blanket bog peat soils	3245	32	0.07%
Improved grassland	Shallow very acid peaty soils over rock	1544	15	0.04%
Improved grassland	Saltmarsh soils	925	9	0.02%

Project Workbook (Targeted Versus Non-Targeted Approach to NELMS Action)

Predicted Carbon Stock Values for a Targetted Scenario Taking In Just Arable or Impoved Grassland

	Spatial Extent of Land Use Class			Soilscapes		Spatial Extent of Soilscape			Carbon Storage			Carbon Stock		Carbon Stock
				Most extensive Soilscape for that land use	Less extensive Soilscape for that land use (at or just above 5% extent)	Most extensive Soilscape for that land use	Less extensive Soilscape for that land use (at least 5% extent)	Range	Most extensive Soilscape for that land use	Less extensive Soilscape for that land use (at or just above 5% extent)	Range	Most extensive Soilscape for that land use	Less extensive Soilscape for that land use (at or just above 5% extent)	Range
LCM 2007	Extent (ha) England	Extent (Km^2) England	As a % of total England	Type	Type	As a % (rounded) of total for that land use	As a % (rounded) of total for that land use	%	t C/ha	t C/ha	t C/ha	t C across 100 Ha	t C across 100 Ha	t C across 100 Ha
Arable and horticulture	6213158	621316	26.54%	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	Freely draining lime-rich loamy soils	21%	6%		242	187	187 - 242	24200	18700	18700 - 24200
Improved grassland	5525587	552559	23.60%	Freely draining slightly acid loamy soils	Freely draining acid loamy soils over rock	22%	7%		208	377	208 - 377	20800	37700	20800 - 37700
Bog*	1006761	100676	4.30%	Blanket bog soils	Naturally wet very acid sandy and loamy soils	87%	<0.01%		1800	337	337 - 1800	180000	33700	33700 - 180000
Littoral sediment*	208049	20805	0.89%	Sand dune soils	Shallow very acid peaty soils o	20%	<0.01%		47	1003	47 - 1003	4700	100300	4700 - 100300

Table Notes: Bog and littoral sediment are shown for comparative purposes

Predicted Carbon Stock Values for a Non-Targetted Scenario Taking In the Top 7 Most Extensive Land Uses

Column Ref. >	-	-	-	-	A	-	-	-	-	B	C	-	-	-
	Spatial Extent of Land Use Class					Soilscapes		Spatial Extent of Soilscapes		Carbon Storage		Carbon Stock		Carbon Stock
						Most extensive Soilscape for that land use	Less extensive Soilscape for that land use (at or just above 5% extent)	Most extensive Soilscape	Less extensive Soilscape (at or just above 5% extent)	Most extensive Soilscape	Less extensive Soilscape	Most extensive Soilscape	Less extensive Soilscape	Range
LCM 2007	Extent (ha) England	Extent (Km^2) England	As a % of total England	% total expressed proportionally across the top 7 land uses	Expressed proprtionally as Ha across 100 Ha	Type	Type	As a % (rounded) of total for that land use	As a % (rounded) of total for that land use	t C/ha	t C/ha	t C for 100ha (A*B)	t C for 100ha (A*C)	t C across 100 Ha
Arable and horticulture	6213158	621316	26.54%	33.2	33.2	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	Freely draining lime-rich loamy soils	21%	6%	242	187	8035	6209	**6209 - 8035**
Improved grassland	5525587	552559	23.60%	29.5	29.5	Freely draining slightly acid loamy soils	Freely draining acid loamy soils over rock	22%	7%	208	377	6142	11132	**6142 - 11132**
Acid grassland	1625523	162552	6.94%	8.7	8.7	Very acid loamy upland soils with a wet peaty surface	Shallow very acid peaty soils over rock	25%	6%	631	1003	5481	8713	**5481 - 8713**
Coniferous woodland	1440050	144005	6.15%	7.7	7.7	Freely draining acid loamy soils over rock	Blanket bog peat soils	16%	6%	377	1705	2901	13121	**2901 - 13121**
Broadleaved, mixed and yew woodland	1318658	131866	5.63%	7.0	7.0	Freely draining slightly acid loamy soils	Shallow lime-rich soils over chalk or limestone	20%	7%	208	314	1466	2213	**1466 - 2213**
Heather grassland	1306177	130618	5.58%	7.0	7.0	Slowly permeable wet very acid upland soils with a peaty surface	Slowly permeable seasonally wet acid loamy and clayey soils	32%	6%	815	243	5689	1696	**1696 - 5689**
Rough grassland	1284092	128409	5.48%	6.9	6.9	Freely draining slightly acid loamy soils	Slowly permeable wet very acid upland soils with a peaty surface	20%	7%	208	815	1427	5592	**1427 - 5592**
Totals	**18713246**	**1871325**	**79.93%**	**100**	**100**	-	-	-	-	-	-	**31141**	**48675**	**31141 - 48675**

Carbon Density in Soils and vegetation By Habitat (from Alonso *et. al*, 2012)

Habitats	Carbon stock in soils (t Cha^{-1})	Carbon stock in vegetation (t Cha^{-1})
Dwarf shrub Heath	88	2
Acid grassland	87	1
Fen, mash and swamp	76	?
Bog	74	2
Coniferous woodland	70	70
Broad leaf, mixed & yew woodland	63	70
Neutral grassland	60	1
Improved grasslands	59	1
Arable and horticulture	43	1
Coastal margins (UK)	48	?

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