UK Centre for Ecology & Hydrology

Moving towards inclusion of coastal wetlands in the UK LULUCF inventory

Rapid assessment of activity data availability

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1 Executive Summary

1.1 Background

Coastal wetlands can play an effective role in climate change adaptation and mitigation, by protecting shorelines and material assets from flooding and storm damage, and trapping and storing carbon dioxide (CO_2) from the atmosphere. They have been subject to high levels of historic modification through drainage and land-use change, which likely contributed to past CO_2 emissions but now represents an opportunity to sequester CO_2 and regain these long-term carbon (C) stores through activities such as rewetting. Sustainably managing these 'blue carbon' habitats, and restoring and recreating habitat where possible, will protect and enhance the benefits they provide. As the UK takes steps to meet its Net Zero target, the role of habitats such as coastal wetlands as nature-based solutions to offset anthropogenic emissions becomes increasingly important. To realise the full potential of these habitats to mitigate climate change, a deeper mechanistic understanding is needed to quantify their capacity to sequester C, and to understand the controls and drivers so carbon stock changes can be predicted and modelled over time.

In 2016, UKCEH reported on the implementation requirements of the 2013 Intergovernmental Panel on Climate Change (IPCC) Wetlands Supplement (IPCC 2014)[1]. The aim of this report was to bring together all available data and information to: (1) enable creation of an adequate base map to track change over time; (2) update on rewetting, revegetation, and creation actions, (3) assess extraction activity; and (4) identify next steps required for data needs to be met for inclusion in the UK Greenhouse Gas Inventory. This rapid assessment is an update to a previous report on IPCC reporting requirements for coastal wetlands (Chapter 4[2], see Appendix 6), with a focus on saltmarshes, and the evidence which is needed for implementation in the UK Greenhouse Gas Inventory (GHGI).

Inclusion of a new habitat in the UK GHGI requires adequate empirical data to track land use and land-use changes that affect habitat condition and biogeochemical function. At the simplest level, if activity data are available, default IPCC Tier 1 emission factors (EFs) can be employed to multiply estimated areas of land in a specific condition, e.g. restored saltmarsh, by the relevant IPCC EF, to estimate anthropogenic impacts on greenhouse gas (GHG) emissions and removals. However, to improve the accuracy of inventory reporting and reduce uncertainties, it is good practice, particularly for key categories, to employ higher tier methodologies, either Tier 2 EFs derived from country-specific published C stock or GHG flux data, or higher Tier 3 process-based models. At present, the UK has very limited evidence of emissions from coastal wetlands, anthropogenic activity data, and evidence of habitat change. As a result, there are multiple evidence gaps (as detailed below), which must be filled before inclusion of coastal wetlands in the UK GHGI can be considered. Inclusion of a new habitat in the UK GHGI involves a procedure of

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[1] https://naei.beis.gov.uk/reports/reports?report_id=980
[2] https://www.ipcc-nggip.iges.or.jp/public/wetlands/draft/Final_Draft_Wetlands_Supplement/Chp_4_FD_Wetlands_Supplement.pdf

rigorous and comprehensive data acquisition; documentation; recommendation for implementation from the National Inventory Steering Committee that governs the UK GHGI, drawing on technical advice from its Land Use, Land-Use Change and Forestry (LULUCF) Scientific Steering Committee; and ministerial approval.

1.2 Key findings

1.2.1 Challenges

- Inconsistent methodological and classification approaches when mapping saltmarsh habitat makes the development of a unified UK-scale base map challenging. Within the report of our rapid assessment, we identify several saltmarsh habitat extent data sources, however discrepancies between them lead to differences in areal extents of habitat. For seagrass, a base map developed at this time would likely be incomplete as habitat around the UK is still being mapped and discovered.
- There are currently insufficient data regarding extraction activities to enable a Tier 1 approach to be implemented and further work is needed to understand the extent to which extraction activities impact coastal wetland habitat. The Marine Management Organisation (MMO) hold data regarding all licenced extraction activities for England, however the data needed for inventory purposes is not easily determined, and would require calculation and investigation on a case by case basis The fate of any removed material would also need to be known, as only material moved from saturated vegetated habitat (predominantly seagrass) to unsaturated (aerobic) conditions would be included.
- There are many data gaps in the current knowledge base around C sequestration and storage within coastal wetlands. To account for coastal habitat in a UK-specific context (Tier 2), EFs would need to be developed using direct measurements of soil C stock and GHG emissions. A co-ordinated approach is needed to fund targeted research to understand the natural gradients in primary, large-scale predictors thought to influence marsh accretion, C storage, and C sequestration across the UK.
- For saltmarsh to be included at the most basic (Tier 1) level in the GHGI, there are two data needs that are not routinely collected whilst monitoring restoration sites. Firstly, changes to habitat extent within restoration sites over time – often only total area is recorded, that can be a mosaic of transitional, terrestrial, and coastal habitat. Secondly, detail on vegetation colonisation rate is needed to estimate change in soil C stock associated with rewetting and revegetation. However, these data needs could be solved by routine observation and recording, or through the use of aerial imagery.
- The current areal extent of coastal wetlands and land area available for restoration both mean the associated emissions and uptake of carbon are estimated to be small in the context of UK totals.

1.2.2 Recommendations

- A definition of what is and is not considered saltmarsh in the UK needs to be made, specifically describing the habitats for inclusion in the GHGI. For example, how to delineate between saltmarsh and mudflat.
- Defining a ‘transitional phase’ – whilst restoration sites are in transition between their former land-use and intended habitat. Including defined criteria for successful land use change. For example, successful rewetting might require the establishment of a recognisable saltmarsh plant communities.
- A habitat base map to enable tracking of change over time needs to be developed bringing together all available data sources, including detail on habitat condition and land-use.
- There is a need to develop a consistent, replicable, standardised method for assessing habitat extent, condition, and change over time, at a national and individual site scale. We recommend a scoping exercise is carried out into the feasibility of using Earth Observation (EO) techniques.
- Addressing the lack of direct GHG measurements (including methane, CH_4) on saltmarsh habitat by a co-ordinated approach to targeted research.
- Develop guidance on the soil depth to use for reporting soil C and if this differs depending on habitat condition, for example restored saltmarsh with sediment overlaying a relic land surface compared to ‘natural’ saltmarsh.
- Extraction activity data needs to be investigated further to better understand the scale at which material from vegetated habitats (predominantly seagrass) which are under anaerobic conditions, is moved to aerobic conditions.

Contents

Acronyms and terminology

ABPmer: a marine consultancy and survey company

Blue Carbon: carbon stored in coastal and marine ecosystems.

Cefas: Centre for Environment, Fisheries and Aquaculture Science is an executive agency of the Department for Environment, Food and Rural Affairs

CH_4: methane

CO_2: carbon dioxide

DAERA: Department of Agriculture, Environment and Rural Affairs, part of the Northern Ireland Executive

DOM: Dead Organic Matter

EA: Environment Agency, an executive non-departmental public body, sponsored by the Department for Environment, Food & Rural Affairs

EF: emission factor

EUNIS: European Nature Information System

GGR: greenhouse gas removals

GHG: greenhouse gas

GIS: geographic information system

HABMOS: Scottish Natural Heritage Habitat Map of Scotland

IPCC: Intergovernmental Panel on Climate Change

2006 IPCC guidelines: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

2013 IPCC Wetlands Supplement: 2014 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands

JNCC: Joint Nature Conservation Committee, a public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation

Lle: Geo-Portal developed as a partnership between Welsh Government and Natural Resources Wales.

MMO: Marine Management Organisation (MMO)

MR: Managed Realignment

NAEI: National Atmospheric Emissions Inventory

NDC: Nationally Determined Contribution

NOC: National Oceanography Centre

NRW: Natural Resources Wales

OMREG: a database of completed coastal habitat creation schemes and other adaptation projects

OSPAR: Oslo/Paris convention (for the Protection of the Marine Environment of the North-East Atlantic

RTE: Regulated Tidal Exchange

Saltmarsh: a coastal ecosystem in the upper coastal intertidal zone (uncovered daily by seawater, as the tide goes in and out) between land and open saltwater or brackish water (water having more salinity than freshwater, but not as much as seawater)**.** Saltmarshes are also known as coastal salt marshes or as tidal marshes.

Seagrass: here used as an abbreviation for seagrass meadows, also called seagrass beds, underwater ecosystem formed by seagrasses. Seagrasses are marine (saltwater) plants found in shallow coastal waters and in estuaries. The grasses live in areas with soft sediment that are either intertidal (or subtidal (always under the water).

SMSS: Nature Scot's Saltmarsh Survey of Scotland

Tier: Three tier's are described for categorizing both emissions factors and activity data. **Tier 1** is the basic method, frequently utilizing IPCC-recommended defaults emission factors, while **Tier 2** reporting is based on similar equations but country-specific emission factors. Tier 3 methods correspond to more complex representations (e.g. with models).

UKCEH: UK Centre for Ecology & Hydrology

UNFCCC: United Nations Framework Convention on Climate Change

2 Introduction

Coastal wetlands formerly covered a greater extent of the UK land area – around 4% of England and Wales, compared to the 0.2% remaining. They have been subject to comparatively high levels of historic modification by drainage and land-use change, which is likely to have contributed to past CO_2 emissions, but which may now present opportunities to sequester CO_2 through activities such as rewetting, land-use change, and managed coastal realignment. In general, saltmarsh and seagrass have not been considered as important habitats for climate mitigation, in part due to its small areal extent. However, due to their high rate of carbon (C) accumulation, and the potential area that could be considered suitable for restoration, the mitigation potential of 'Blue Carbon' in the UK could be reconsidered and included in future updates of the UK Nationally Determined Contribution (NDC).

In 2016, UKCEH reported on the implementation requirements of the 2013 IPCC Wetlands Supplement for coastal wetlands (chapter 4). This report is included here in Appendix 6.

The key findings were:

- All formal rewetting of saltmarsh has happened since 1990, and therefore comprehensive data are available.
- Detailed information regarding past drainage of saltmarsh is not available and estimates can only be made by overlaying soil and land-use maps. However, this drainage is historic (majority took place in the 1700s and 1800s) and therefore reporting is not needed.
- There are currently insufficient data regarding rewetting/restoration and/or extraction of seagrass beds.
- There are currently insufficient data regarding extraction activities. Sudden increases in these activities have the potential to cause large emissions given the assumption that all carbon will be emitted as CO_2 during the same year as extraction.
- Reliable and complete spatial data is needed for saltmarsh and seagrass extent, and change over time.

This rapid assessment is to update the coastal wetlands part of the 2016 report, with an overall aim to make the best possible progress on documenting whether coastal wetlands, focussing mainly on saltmarshes and to a lesser extent on seagrass here, should potentially be reported in the UK by:

- Bringing together all available data to enable creation of an adequate base map to track change over time.
- Updating rewetting, revegetation, and creation activity information and reviewing data sources.
- Finding and reviewing information and activity data regarding extraction activities.

3 Creation of base map

The extent of saltmarsh habitat in the UK is currently estimated to be between 40,000 and 45,000 ha. Within our previous report, we estimated an annual loss rate of around 4% between 1988 and 2009. However, this was based on results of survey data employing different methodologies, so is hard to verify. Saltmarsh area reflects an equilibrium between erosion and accretion, and it is therefore difficult to accurately estimate the extent of saltmarsh at a particular time in the past. The estimated extent of saltmarsh in these datasets are a reflection of presence at some point over a sampling period, which usually spans multiple years for country-wide assessments. It is possible that some areas reported as saltmarsh early in the sampling campaign are no longer saltmarsh. However, we will need to assume that those areas remain as saltmarsh for that period.

In order to include saltmarshes in the UK GHG inventory, it will be essential to develop a base map of saltmarsh condition and land use to enable tracking of change over time. We have identified a number of data sources presented in the accompanying excel file – outlined in appendix 2. However, again due to methodological and classification differences, areal extents differ. Changes in saltmarsh condition due to restoration will need to be assessed from other sources (see sections 3 and 4), cross-checked with areal imagery, and accounted for in the year in which the actions occurred.

JNCC's UK Combined EUNIS (European Nature Information System) level 3 habitat map for habitats in the offshore marine environment provides areas of coastal saltmarshes and saline reed beds (taken as a synonym for saltmarshes in the figures of section 2 and annex 5) under EUNIS category A.2.5, and estimates the combined area to be 14,745 ha. These areas are accounted for to some degree in the country-level datasets outlined below and in appendix 2, and therefore further analysis to overlay the EUNIS dataset with others, removing duplicated areas, is required to avoid double-counting of saltmarsh habitat in the base maps.

3.1 England

Areas for inshore blue carbon habitats (above the mean high water mark) for England can be taken from the Environment Agency's (EA) saltmarsh extent and zonation maps, which represent 34,450 ha of saltmarsh habitat collated between 2006 and 2019, 85% of which has been put into saltmarsh zones (Figure 1). The area of saltmarsh estimated in the EUNIS dataset for England totals approximately 7,555 ha, which overlaps the EA saltmarsh extent particularly in the region of The Wash (see Appendix A5.1 for further detail). An update to the EA dataset was published in December 2021. As part of the Cefas Carbon stocks and accumulation analysis, a combined saltmarsh and saline reed bed extent of 11,000 ha for England is reported citing Flavell *et al.*, (2020). It is understood that the spatial data associated with this estimate will be published by JNCC (Pers. Comm. Laura Harland, Defra 28/04/2021).

The only relevant seagrass extent layer identified is the EUNIS dataset. Historic point locations of seagrass in England, or where seagrasses are highly degraded are available from MMO (2020), and other occurrence datasets exist (e.g. UNEP_WCMC, Short FT (2021), but these would need to be reconciled to create a national map.

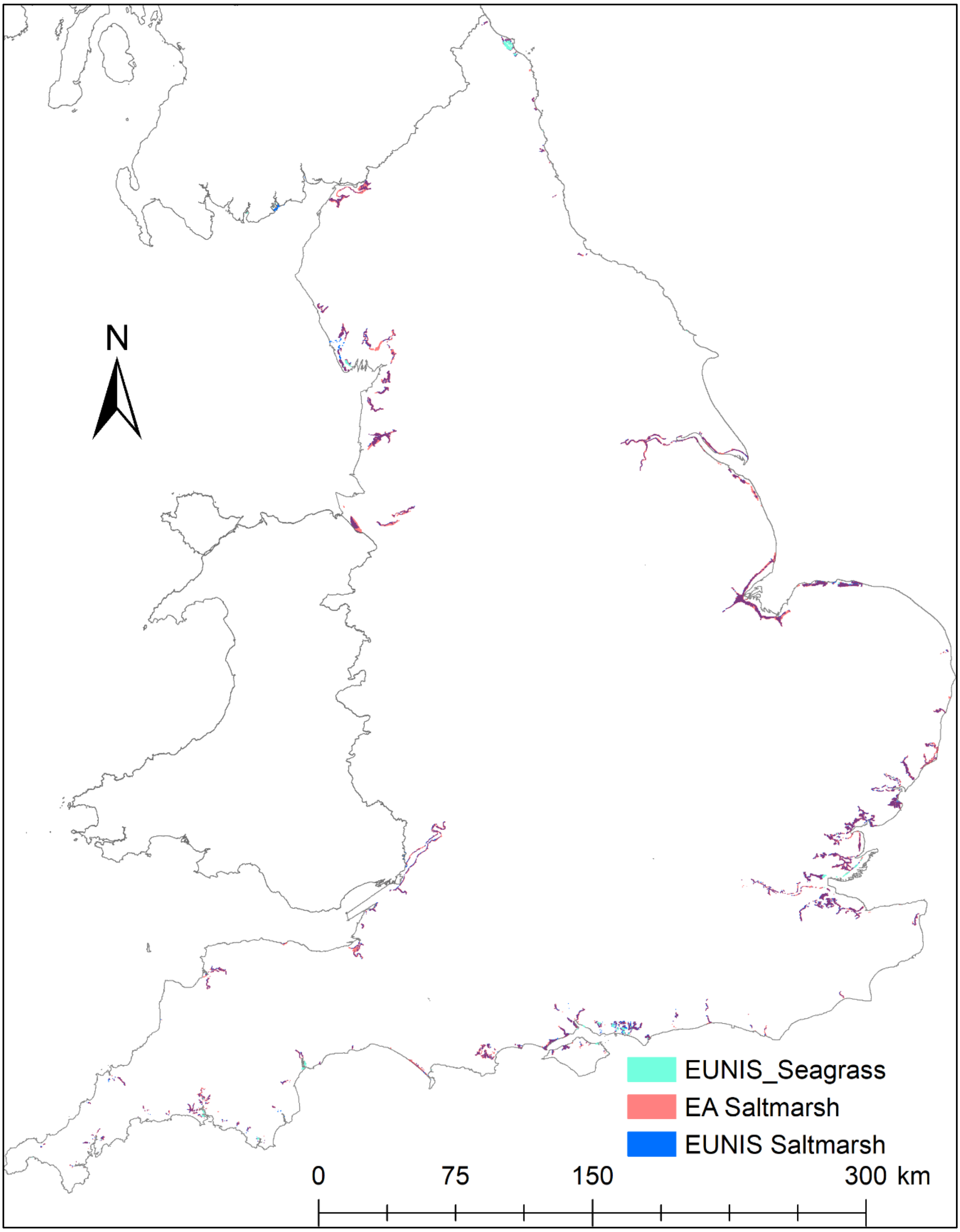


Figure 1. *Estimated extent of saltmarsh and seagrass in England, showing overlap (in purple, 50% transparency applied to EA layer) between the EUNIS and EA datasets*

3.2 Scotland

Nature Scot's Saltmarsh Survey of Scotland (SMSS) is the most up to date saltmarsh extent map, and encompasses all known saltmarshes greater than 3 ha surveyed from 2010 to 2012. This dataset estimates the extent of saltmarsh in Scotland to be 5,868 ha. Older datasets produced by Scottish Natural Heritage (HABMOS and Phase 1 Scotland) are also available, shown in Figure 2 and Appendix A5.2, however the areas of saltmarsh are substantially lower (594 and 811 ha, respectively) compared with the Nature Scot survey. Also, the EUNIS dataset appears to capture additional saltmarsh habitat, totalling 957 ha. Further analysis is required to assess how these layers differ and whether a unified map can be produced.

The only relevant seagrass extent layer identified is the EUNIS dataset.

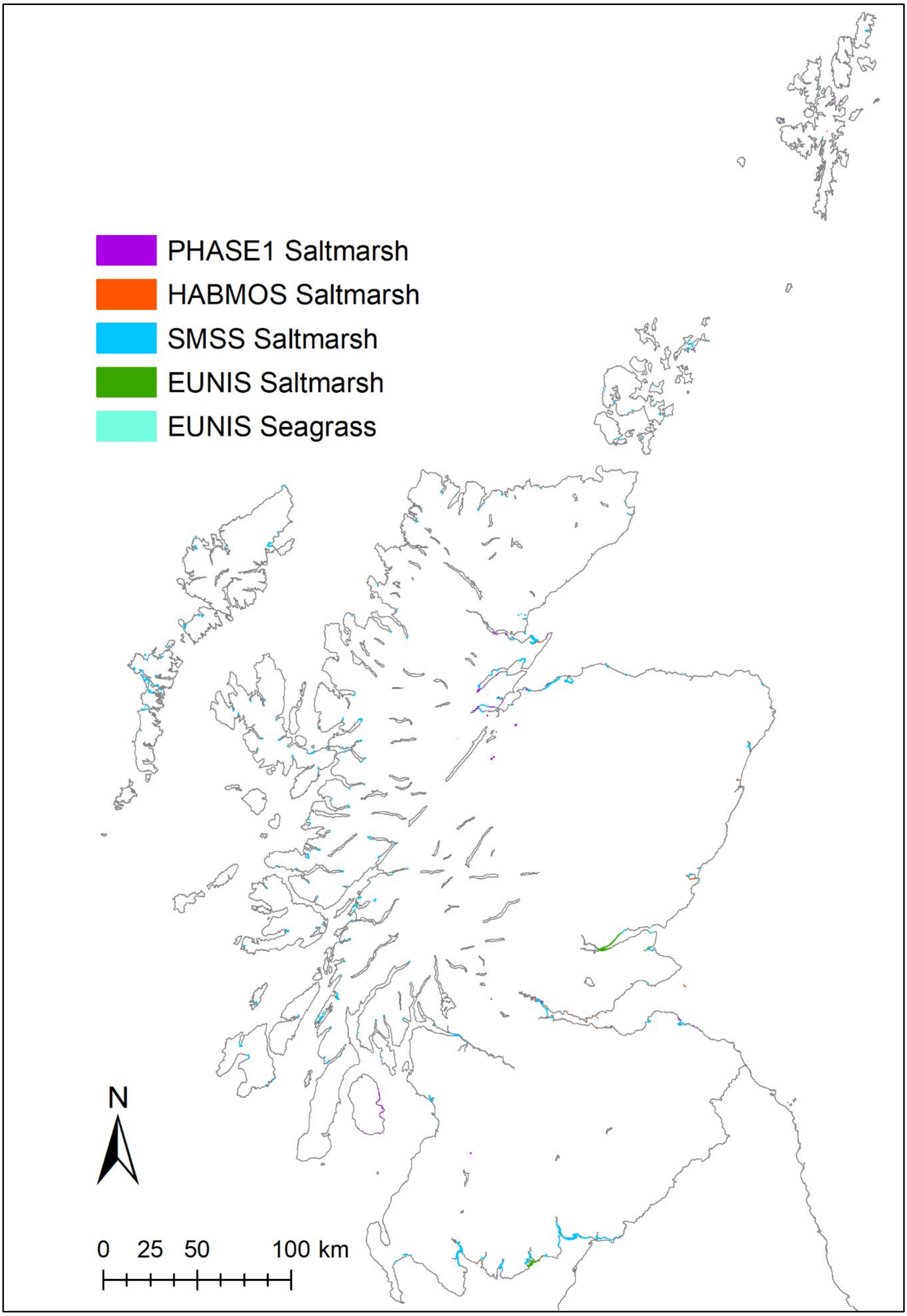


Figure 2. *Saltmarsh and seagrass extent in Scotland from the Nature Scot Saltmarsh Survey of Scotland (SMSS), Scottish Natural Heritage (HABMOS and Phase 1 Scotland), and the EUNIS habitat map.*

3.3 Wales

Two Natural Resources Wales (NRW) datasets of saltmarsh extent are available for Wales, covering the periods from 1996 to 2005 and 2009 to 2017. These layers provide estimates of saltmarsh area totalling 4,966 ha and 8,261 ha, respectively (Figure 3, Appendix A5.3). The area of saltmarsh estimated in the EUNIS dataset for Wales totals 6,233 ha, which overlaps the NRW saltmarsh extent. These datasets require further evaluation to assess the cause of changes between years e.g. due to land use change, loss/accretion, differences in sampling methodology. In addition, the Phase 1 Intertidal Biotypes layer provides information on seagrass extent, which is estimated to total 429 ha. There are also seagrasses in Wales reported in EUNIS.

The NRW maps also include some saltmarsh areas that fall outside of the Welsh border in northwest and southwest England. These have been deducted from the total reported for Wales, but the Welsh saltmarsh datasets should be superimposed on the England layers to ensure they are captured there.

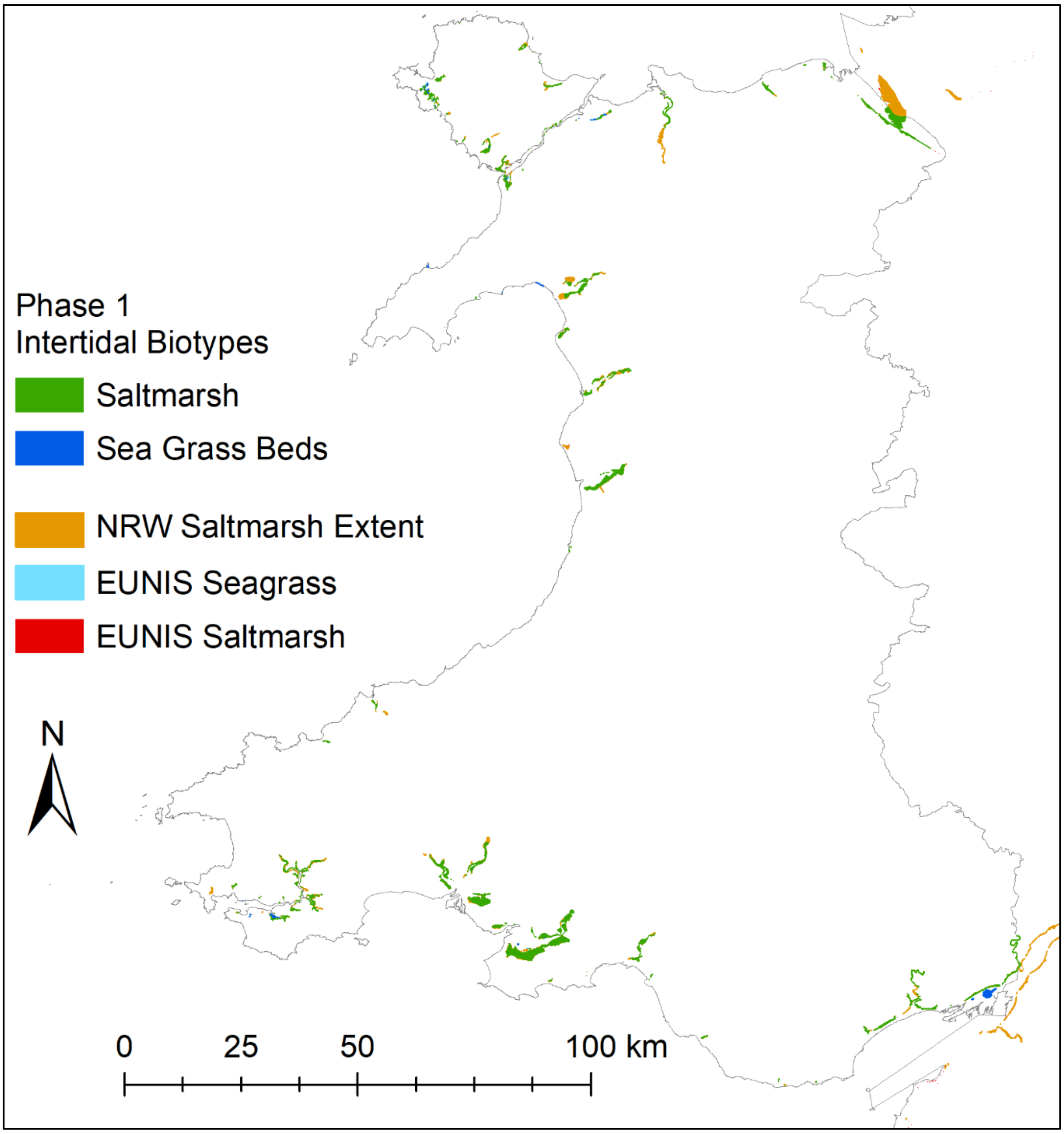


Figure 3. *NRW estimated extent of saltmarsh and seagrass in Wales from the 1996 to 2005 Phase 1 Intertidal Biotypes layer, and saltmarsh from 2009 to 2017 (orange).*

3.4 Northern Ireland

A new DAERA dataset of saltmarsh and seagrass extent was identified for Northern Ireland (Strong *et al*. in prep), which could be used as a basemap in the inventory as received (Figure 4; Appendix A5.4).). Maps of the current extent and habitat suitability are available from this project. The extent of saltmarsh and seagrass species and habitat are estimated to total 3,108 ha, and 1,570 ha, respectively, which is based on data from 1980 to 2020 and assumes that areas remain occupied for the estimated period. An additional 140 ha of seagrass attributed to *Zostera noltei* is estimated in the DAERA report, however this species is considered sparse and ephemeral due to grazing by migratory geese and is therefore difficult to assess. It is recommended that this species is excluded from estimates of seagrass extent in Northern Ireland (Pers. Comm. James Strong, NOC 02/03/2021), however this may not be appropriate for all devolved administrations, and *Zostera noltei* could be considered present if its areal extent is found to represent more than 10% of the same area on a time average. No further spatial datasets were identified for Northern Ireland.

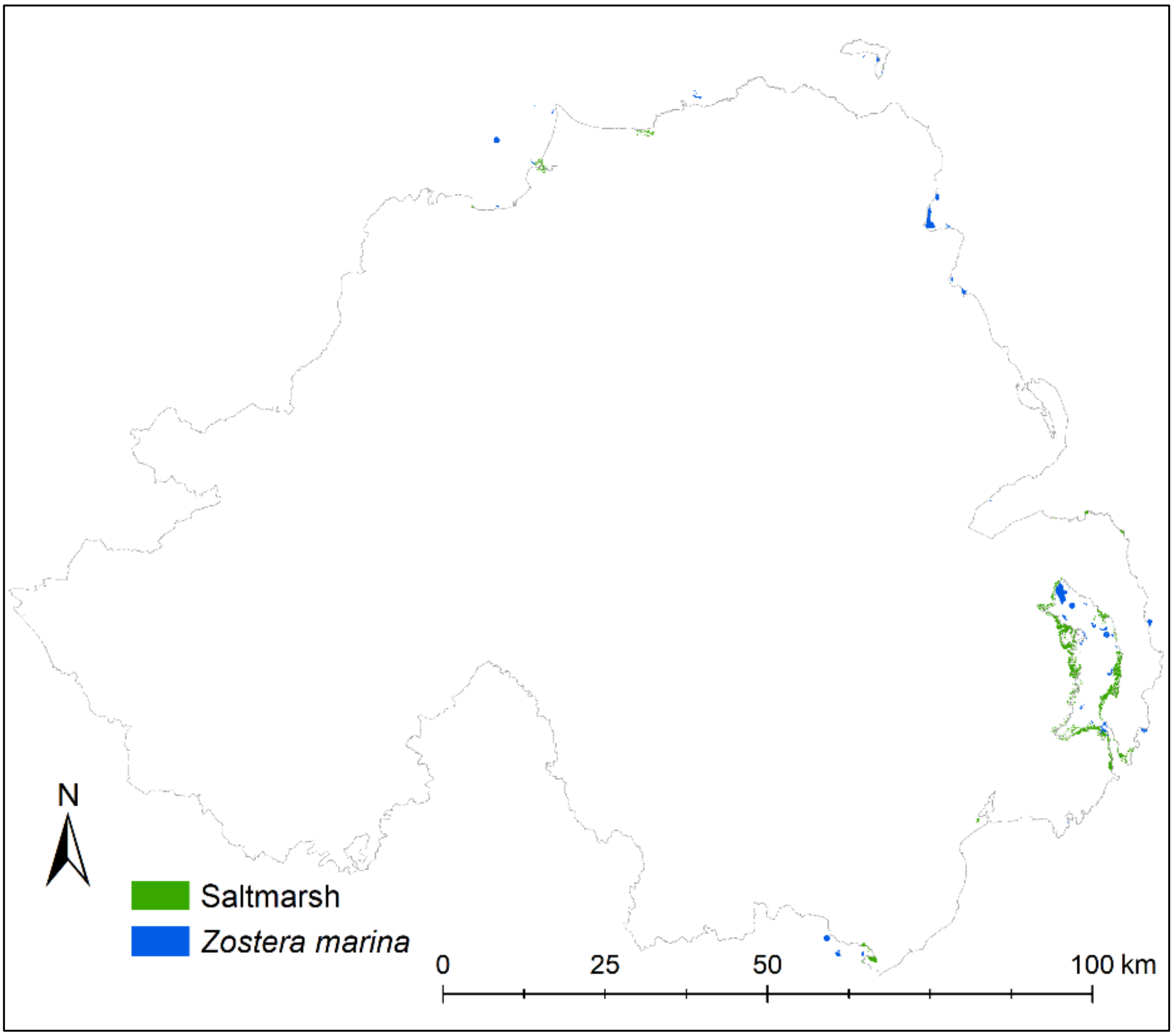


Figure 4. *Estimated extent of saltmarsh and seagrass species in Northern Ireland from 1980 to 2020 provided by DAERA.*

3.5 Identified next steps

1. All collated saltmarsh and seagrass spatial layers for the UK require further evaluation of condition, for example by:
    - Overlaying with land-use, extraction sites, and rewetting/restoration site information.
    - Use of satellite imagery to verify rewetting and extraction sites.
    - Cross-checking with inventory organic soil maps.

2. A consistent survey methodology would also provide more accurate estimates of trends and extent over time, and more easily allow changes due to land-use change to be accounted for. Earth Observation (EO) techniques such as digital image classification and Lidar would provide this methodology, as they do for tracking change in peatlands. The use of satellite imagery has the potential to provide a replicable, standardised methodology for assessing extent, condition and change over time at a national scale. Its relative low-cost, compared to traditional ground-based monitoring methods, also make it an attractive prospect, although time from a highly skilled person is still needed. Earth observation can also help fill the gaps in data originating from on the ground measurements. For example, those highlighted in section 3.1. Lidar data could potentially also be used to indicate whether dredged material had been added to sites above sea level, another data gap pertaining to extraction discussed in section 4.2.

    It is recommended here that a scoping exercise into the feasibility of using these techniques for coastal habitat is undertaken.

4 Rewetting, revegetation, and creation activity

The OMREG online database (https://www.omreg.net/) is a free resource documenting completed coastal habitat creation schemes and other adaptation projects. It is maintained by ABPmer who collate rewetting and restoration activity in the UK (and some worldwide), with the only criteria being the project must be complete (Figure 5). Although this database may not include all habitat creation activity, it contains the vast majority and is the best resource for this information. ABPmer plan to also include creation of seagrass and oyster reef habitats in the near future.

Information sheets per project include:

- Scheme type
- Grid reference
- Total area
- Year
- Habitats created

To date (1991-2021) 3,006 ha have been created in the UK either by:

- Managed Realignment (MR) – the landward retreat of coastal defences and subsequent tidal inundation of reclaimed land.
    - 53 projects, 2,546 ha
- Regulated Tidal Exchange (RTE) – where sluice gates or culverts are used to create new intertidal habitat behind permanent sea defence structures.
    - 24 projects, 460 ha

The suitability maps associated with the DAERA saltmarsh project may have future use for determining restoration or habitat creation sites, however according to DAERA (Aideen McChesney Pers. Comm. 01/03/2021), there are currently no managed realignment sites in Northern Ireland.

4.1 Data gaps

Some data needed for a tier 1 approach are still lacking:

- The site areas within the OMREG database, and therefore the quoted extent of rewetted, restored, or created habitat are taken as the total area between the old sea defence that has been breached (or within which a regulated tidal structure has been installed) and the new landward border. However, this quoted area is not always all coastal habitat. It can include areas of transitional grassland, and agricultural land not flooded by the tide. An assumption that all land affected by MR or RTE reverts to coastal habitat could lead to inaccurate emissions estimate. To account for land-use change correctly, detailed area data would be needed for each habitat within these sites, to allow for separate reporting.

- No change in soil carbon stock is assumed until at least 10% of the area has been colonised by vegetation. This data is not reported within the OMREG database and can only be inferred if suitable data is within the published literature, and even then may not be representative of other sites as speed of colonisation will be variable. Low lying sites especially will need a number of years of accreting sediment before the tidal elevation is suitable for plants to establish. Further information will be needed on any active revegetation programs and post-restoration management, which may be available from project managers.

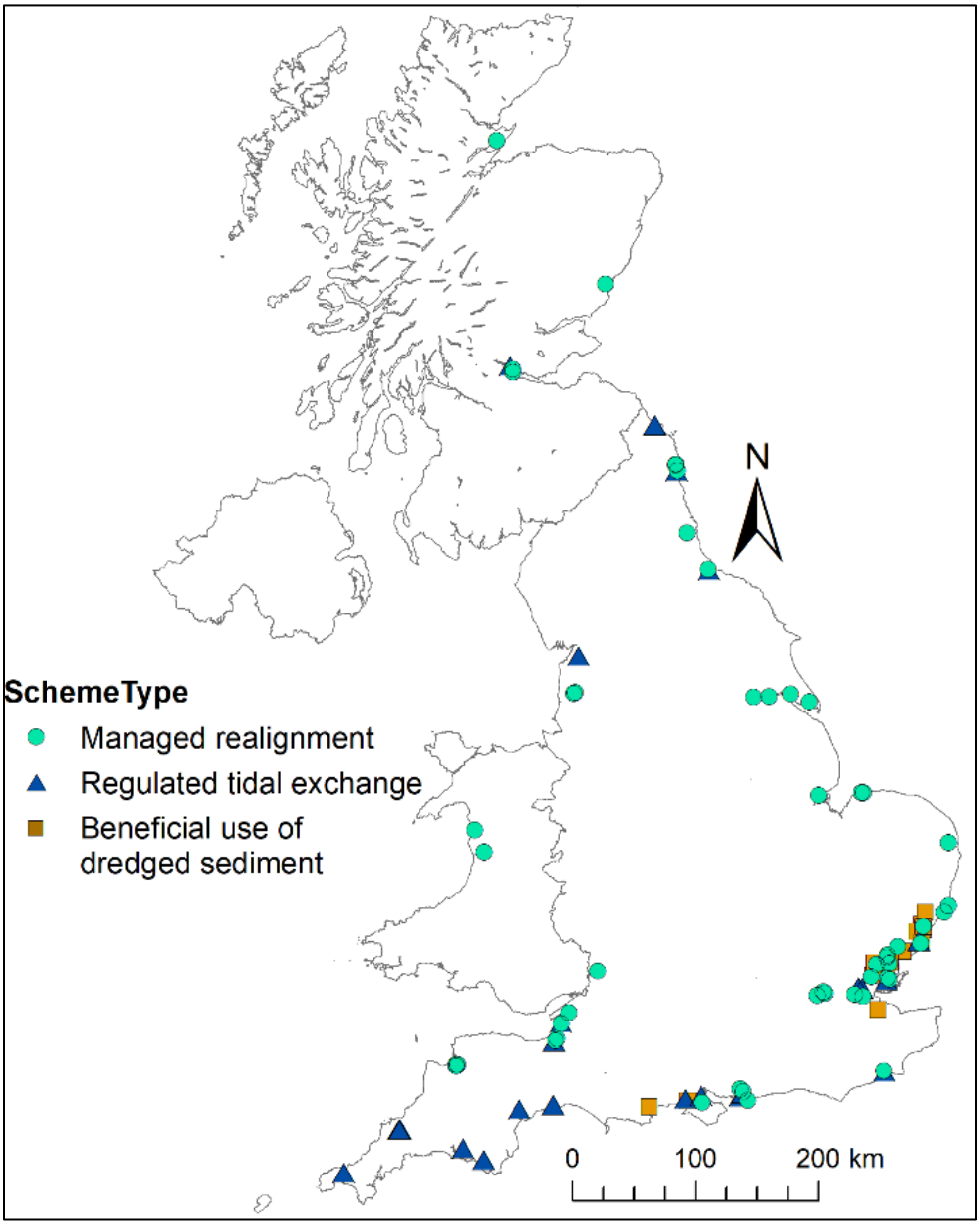


***Figure 5**. Location of coastal habitat creation schemes (managed realignment and regulated tidal exchange) and beneficial use of dredged sediment, which have project information held in the OMREG database*

Table 1. *Activity data (in addition to spatial extent data) needed for Tier 1 and 2 emission estimates from rewetting, revegetation, and creation of saltmarsh and seagrass beds. Default emission factors taken from the 2013 IPCC Wetlands Supplement for coastal wetlands (chapter 4).*

	Tier 1	Tier 2
Biomass	No data needed. Assumes no change in biomass stock as a result of rewetting.	▪ Annual above-ground increase due to biomass growth ▪ Annual above-ground decrease due to biomass losses ▪ Carbon content of dry biomass ▪ Proportion of woody and herbaceous biomass
Dead Organic Matter (DOM)	No data needed. Assumes no change in DOM as a result of rewetting	▪ Two DOM pools to address separately. ▪ Average annual transfer of biomass into and decay out of each pool due to processes and disturbances ▪ Carbon fraction of each pool
Soil Carbon	Estimate of when 10% of the overall area is colonised by vegetation. Default EF once this requirement is met = -0.91 t C ha^{-1} yr^{-1} for saltmarsh and -0.43 t C ha^{-1} yr^{-1} for seagrass. Table 4.12.	UK-specific emission factor disaggregating organic and mineral soil type
Non-CO_2 emissions	Assumes no non-CO_2 emissions as a result of rewetting if the salinity is greater than 18ppt	▪ Assumes no non-CO_2 emissions as a result of rewetting if salinity is greater than 18ppt ▪ UK-specific CH_4 emission factor based on water salinity if less than 18 ppt

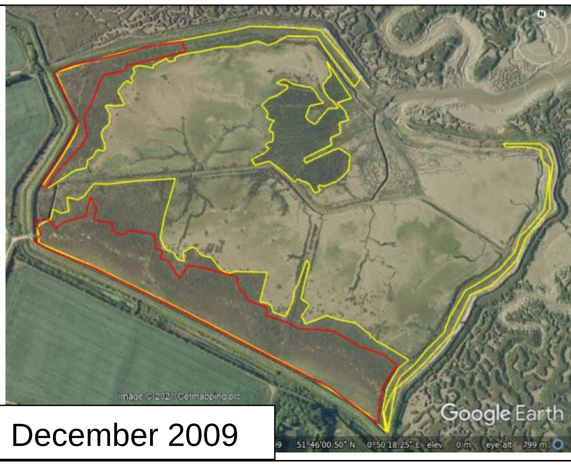
4.2 Tracking change over time

To address the two points in section 3.1, a simple exercise in Google Earth provides the information needed to record area of specific coastal habitats within restored sites, see how these change over time, and estimate when at least 10% of the area has been colonised by vegetation. The Tollesbury Managed Realignment site (Blackwater Estuary, Essex) is used here as an example. The 21 ha site was implemented in August 1995 and is described in the OMREG online database as mudflat and saltmarsh. Google Earth images from 5, 14, and 23 years post restoration were selected and polygons drawn around permanent vegetation within the site (Figure 6 – further images in Appendix 3). Total saltmarsh area within the site was estimated at 3, 6.3, and 14.8 ha, highlighting the need for more detailed habitat extent data within sites to estimate emissions and removals correctly.

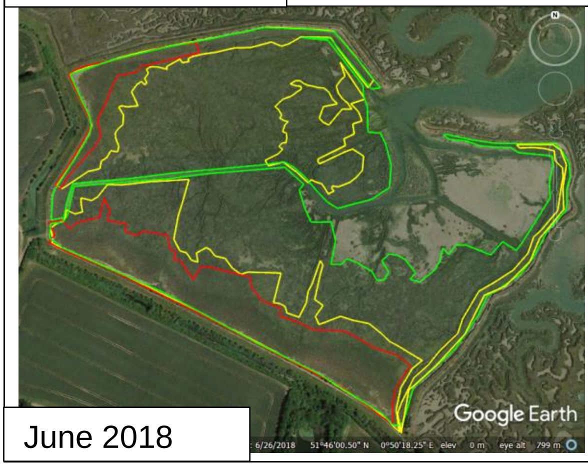
The main drawbacks of this method are the quality and infrequency of the images (see Appendix 3), particularly in regards to controlling apparent differences due to season and tide. However, it is quick to achieve estimates, with no additional GIS/satellite data processing skills needed, and no extra cost apart from staff time.

We would still recommend exploring remote sensing techniques as a survey methodology to track change and condition of salt marsh over time (as mentioned in section 2.1), but this quick and easy exercise would provide the information needed for a Tier 1 assessment of the 77 restoration sites (MR and RTE) created to date.

December 2000



December 2009



June 2018

Date	Saltmarsh areas (ha)	Total (ha)	Years after restoration
December 2000	0.61 2.37	2.98	5
December 2009	1.45 3.53 1.00 0.29	6.27	14
June 2018	6.69 8.14	14.83	23

Figure 6. *Example of tracking change over time in a Managed Realignment site (Tollesbury, Blackwater Estuary, Essex) using Google Earth imagery.*

4.3 Identified next steps

1. Further investigation of project data. For example, the Allfleet's Marsh project is identified as a managed realignment site, but within the project description text it states: "A large-scale sediment recharge was undertaken (550,000 m^3) at the back of the site to raise the land-form to create saltmarsh", suggesting this is also a site of beneficial use of dredged material.

   The text also gives information regarding any pre- and post- restoration monitoring which could help inform on transition rate of habitat.

2. Differences in likely emissions between managed realignment and regulated tidal exchange sites should be investigated and separate emission factors developed.

3. Guidance on the soil depth to use for reporting soil carbon should be developed as many different depths are reported within the literature. Within the 2006 IPCC guidelines, chapter 2 "Generic methodologies applicable to multiple land-use categories", a default depth of 30cm is defined for Tier 1 reporting. It also states greater depths can be used at Tier 2 if data are available. A depth of 1m is used inland in the Land-Use Change soil model currently used in the UK GHG inventory.

4. As part of the Environment Agency Saltmarsh Restoration handbook published in November 2021, advice is given regarding pre- and post-restoration monitoring to align data collection with inventory reporting needs. The identified data gaps in section 3.1 above will therefore become part of recommended routine data capture moving forward.

5 Extraction

Extraction relates to activities where material is removed from soil of vegetated coastal ecosystems characterised by saturated (water-logged) conditions and deposited in unsaturated (aerobic) conditions. The wetlands supplement guidance assumes all carbon will be emitted as CO_2 during the same year as extraction. In a UK context this refers collectively to excavation associated with dredging (sometimes to provide material to raise the elevation of land – section 4.2); or to enable port, harbour, and marina construction and maintenance.

The Marine Management Organisation (MMO) maintains a register containing all Marine Licences and Applications data for England (although, it is worth noting that in some instances, operators of harbours and ports have their own powers to dredge and may only need a license to dispose of dredge material). The data is publicly available and contains spatial data sets, illustrated in Figure 7. However, the activity data needed here (extraction associated with dredging that impacts saltmarsh and seagrass, as explained above) is not available as separate categories, and so could be split between many. For example “construction of new works”, “emergency work”, and “maintenance of existing work” could all include construction and/or maintenance work impacting on coastal habitats, making it hard to narrow down the 100s of projects by activity type.

Here we have extracted the location data needed to identify where extraction activities have occurred (as, on investigation, this was not part of the available downloaded dataset). There are 618 projects covering the time period 2002-2020, which have been narrowed down to 252 potential sites within a 1km distance of the coastline. This data set has been submitted alongside this report, outlined in Appendix 2. These potential sites all need further investigation via Google Earth to visually check if they intersect with saltmarsh or seagrass habitat. If they do, the licence number (available as part of the MMO dataset) would allow cross-reference through the MMO public register to access more information (potentially volume and/or area affected – a README tab in the submitted excel file explains how to find further information for each case). Once a saltmarsh base map has been developed/agreed upon, this could be overlaid with the extraction data as another way to check and/or narrow down which extraction projects to investigate further.

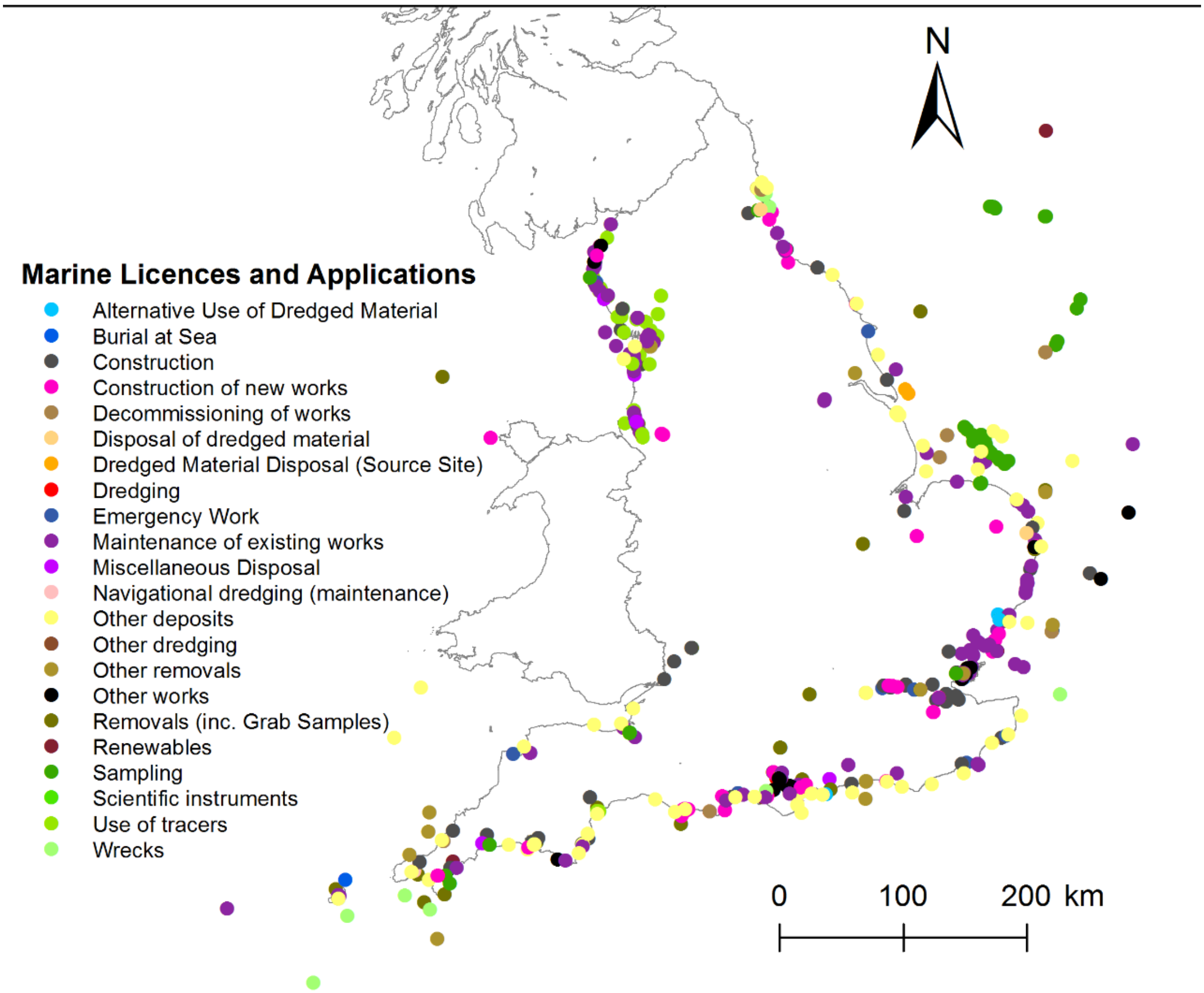


Figure 7*. Extract of Marine Licences and Applications data collated and held by the Marine Management Organisation (MMO). Points show the locations of licenced extraction activities.*

Another identified possible avenue to gather information is through the MMOs reporting for OSPAR. They report amount of dredge material against each licensed deposit site and licence number every 6 months. However, after receiving and investigating the last 6 years' worth of data (2015-2020), none of the sites intersect with activities within 1km of the coast, and therefore we didn't feel it was relevant for the activity data needed.

In Wales, NRW acts on behalf of the Welsh Government to issue marine licenses. Similar spatial datasets are available on Lle and the Marine Planning Portal, information about which is included in the accompanying data set information spreadsheet.

***Table 2**. Activity data (in addition to spatial extent data) needed for Tier 1 and 2 emission estimates arising from extraction of soil and sediment used to raise elevation of land and enable port, harbour and marina development. Default emission factors taken from the 2013 IPCC Wetlands Supplement for coastal wetlands (chapter 4).*

	Tier 1	Tier 2
Biomass	▪ Change assumed to be zero for Coastal Wetlands without perennial biomass ▪ If perennial biomass present, stock after conversion presumed to be zero	▪ Above-ground biomass before activity ▪ Above-ground biomass after activity ▪ UK-specific ratio of below-ground to above-ground ▪ Carbon fraction of dry matter ▪ Evaluation of assumption all oxidised in same year as activity
Dead Organic Matter (DOM)	No data needed. Changes assumed to be zero	▪ Evaluation of assumption all oxidised in same year as activity ▪ UK-specific dead organic matter carbon stocks for Coastal Wetlands with perennial biomass
Soil Carbon	No data needed. Defaults provided: 255 t C ha^{-1} for saltmarsh in general (340 t C ha^{-1} on organic soils, 226 t C ha^{-1} on mineral soils) and 108 t C ha^{-1} for seagrass Table 4.11.	▪ Knowledge of soil type (organic or mineral) ▪ Evaluation of 1m extraction depth assumption ▪ UK-specific soil carbon stock to disaggregate soil type ▪ UK-specific emission factor to disaggregate soil type

5.1 Data gaps

There are currently insufficient data regarding extraction activities to enable a Tier 1 approach to be implemented. Area extents of all activities impacting saltmarsh and seagrass are needed. The ultimate fate of the removed material also needs to be known, as only material moved from saturated vegetated habitat (predominantly seagrass) to unsaturated (aerobic) conditions would be included.

5.2 Beneficial use of dredged material

Some rewetting and restoration of former saltmarsh starts with raising the land surface level before re-connecting to the tide – known as ‘sediment recharge’. If the material used is derived from dredging that impacts seagrass, this would also fall within the remit of extraction activities, and provides a beneficial use of an otherwise waste material. Dredged material is also used for intertidal restoration projects, placed on eroding saltmarsh to avoid further loss of habitat. If the dredging does not impact seagrass (originates from the seafloor) it would not be included in a Tier 1 approach. Sediment recharge could be proposed as an additional management activity requiring development of country-specific Tier 2 emission factors.

Despite approximately 40 Mt of material being dredged annually from sites around England, less than 1% is used for intertidal restoration projects. The IPCC guidelines state that significant emissions could result from dredging activities when material is removed from saturated (water-logged) conditions and deposited in unsaturated (aerobic) conditions, and assumes all carbon will be emitted as CO_2 during the same year as extraction. This additional emission from the dredged material would need to be estimated and would be reported in the year of deposition on the land only. The benefits of preserving the restored habitat would be captured via estimating GHG removals from the saltmarsh areas, which over time would offset the initial emissions from extraction.

The OMREG online database collates beneficial use projects (as shown in Figure 7), and can be considered the most comprehensive collation of activity data available. Operational approach (method), year of activity, and volume of material are given for most projects. However, the volume of material used does not necessarily correspond to the amount of material above sea level (i.e. subject to aerobic decomposition), making emission estimates difficult to calculate. The operational approach gives an indication of how much material is likely to be aerobic, for example, sediment placed on the marsh vs in the lower intertidal and left to dissipate. The latter approach could be presumed to stay anaerobic below sea level. Table A4 (Annex 4) summarises the available information. Since 1990, available data on beneficial use of dredged material cover 336,800m^3 remaining in anaerobic conditions and that 1,042,975m^3 have been moved to aerobic conditions (although 8 projects give no volume information). The IPCC default emissions factors for a Tier 1 approach to extraction activities requires data in tonnes carbon per hectare. However, beneficial use of dredged material is rarely expressed in this way. To develop the Tier 2 data and emission factors to account for this activity, assumptions would either need to be made regarding the equal placement of material across sites, or emissions calculated based on amount/weight of material presumed to be moved to aerobic conditions. This latter approach would require knowledge of the carbon content of the material being deposited. By how much the surface level of the land is being raised would also need to be known as the amount of material subject to aerobic decomposition is the key information needed.

The MMO data illustrated in Figure 7 also contains “alternative use of dredged material” categories which will include sediment recharge projects. This could be cross-checked against the OMREG database.

5.3 Identified next steps

1. As dredging activities are much more likely to affect seagrass beds, the activity data needed here relies on knowledge of their location and spatial extent. Until an adequate base map for seagrass has been developed, it is difficult to determine which dredging activities to include.
2. To get to the activity data needed, the MMO data would require case specific investigation. Each entry contains a licence number which would allow cross-reference through the MMO public register to access volume and information on where the dredged material originated from and was deposited. The data set has been submitted alongside this report, outlined in Appendix 2.
3. The MMO dataset contains information for England only and covers 2002-2020. Information regarding extraction from 1990 would also need to be sourced and analysed, along with information for all devolved nations.

6 Development of new emission factors (EFs)

IPCC default Tier 1 EFs are neither country, region, nor soil-type specific, and development of Tier 2 EFs would be needed to allow UK-specific emissions to be determined. Tier 2 EFs for saltmarsh condition would also allow for separate assessment of restored saltmarsh, both during transition, and once established. There is an emerging understanding of how carbon accumulation rates change with rewetting of former saltmarsh, either via managed realignment or accidental breaching during storms.

Guidance given in Chapter 4 (Coastal Wetlands) of the 2013 IPCC Wetlands Supplement suggests that “inventory compilers need only report GHG emissions or removals for activities where the anthropogenic contribution dominates over natural emissions and removals”. This would require to track areas that “were drained coastal wetland and are now being rewetted or managed to create or re-establish natural vegetation” and report emissions and removals from those using equations 4.7 and 4.9 of the 2013 IPCC Wetlands Supplement. The EF for carbon stock changes to be used in equation 4.7 could be estimated not only from sites being restored, but could correspond to an EF for near-natural saltmarsh more generally, consistent with the assumption that “the rate of soil carbon accumulation is instantaneously equivalent to that in natural settings” made to establish the Tier 1 EF. To further increase transparency, the UK could report areas of naturally occurring saltmarsh and note that emissions and removals for those areas are not reported.

This approach would be more restrictive than the approach used inland, which is based on the Managed Land Proxy to estimate anthropogenic emissions and removals, where “managed land as land where human interventions and practices have been applied to perform production, ecological or social functions, and all emissions and removals from managed land are to be reported regardless of whether they are anthropogenic or non-anthropogenic” and was confirmed in the 2013 IPCC Wetlands guidance (Section 1.3). This is because it is impractical at the country-level to distinguish between areas that are dominated by anthropogenic emissions and those that are more natural.

If the “land-based” approach used inland and including “near-natural” land was applied to near natural saltmarsh, beyond the area of land currently reported by the UK, the [source or] sink in near natural saltmarsh could also be included in the GHG inventory. While this would not be fully consistent with the restrictive approach suggested in chapter 4 of the 2013 IPCC Wetlands Supplement, this would follow the approach used by the UK for naturally functioning peatlands, for which emissions and removals are reported in the UK inventory. This would also be consistent with the approach used by the USA in its reporting for tidal marshes over the last few years, which applies the average carbon sink across all areas of vegetated coastal wetlands. Expert Review Team mandated by the UNFCCC have not raised recommendations to revise that approach so far (cf the assessment review report of the USA 1990-2017 inventory).

Development of EFs is very much dependent on data availability. In Appendix 1, five recent reviews of the current evidence base for carbon storage and sequestration are highlighted:

- Cefas: Carbon stocks and accumulation analysis for Secretary of State (SoS) region. Includes all devolved nations.
- Natural England: Carbon storage and sequestration by habitat: a review of the evidence (second edition). England only.
- NRW: Estimating the Carbon Sink Potential of the Welsh Marine Environment. Wales only.
- Smeaton, C., Austin, W. and Turrell, W.R. 2020. Re-Evaluating Scotland's Sedimentary Carbon Stocks. Scottish Marine and Freshwater Science Vol 11 No 2, 16pp. Scotland only.
- O'Connor et al: Impacts of land management practices on blue carbon stocks and greenhouse gas fluxes in coastal ecosystems – A meta-analysis. Global data.

A further paper (Burden et al: Effect of restoration on saltmarsh carbon accumulation in Eastern England) is also highlighted as this contains a model based on empirical data to predict change in carbon accumulation in restored sites over time (based on soil carbon data). This could form the basis of new EFs for restoration of saltmarsh and the changes in condition over time. For example, it may be appropriate to develop a specific EF for a period of time whilst restoration sites are in transition between their former land-use and saltmarsh habitat. After a specified number of years post restoration, the definition of the transitional EF, and the assumptions it is based on could be checked to inform if a change of EF is needed. The suggested use of Google Earth imagery to track change over time in restoration sites could help make these decisions.

However, there is still a lack of direct GHG measurements on saltmarsh habitat which is key to developing further EFs, and more targeted funded research is needed. There are two Eddy Covariance CO_2 flux data sets available for saltmarsh habitat (both available through the Environmental Information Data centre, www.eidc.ac.uk):

1. Abbotts Hall. A small restricted embayment salt marsh. Blackwater Estuary, Essex, South East England.
    - doi.org/10.5285/8cfd9a2a-8b68-40c6-94a1-be8e02e869c1
2. Cartmel Sands. 3.2 km long and 1 km at its widest point. Morecambe, North West England.
    - doi.org/10.5285/a4192575-e91a-477d-8f64-aae3b32faf7a

These datasets provide a comparison between South East (muddy) vs North West (sandy), but more data would be needed to fully understand marsh soil type, and to represent the natural gradients in primary, large-scale predictors thought to influence marsh accretion and carbon storage across the UK.

The current NERC C-SIDE project (Appendix 1) selected seven representative regions to measure carbon stock and accretion rates to cover the primary predictor variables, which were stated as:

- Relative Sea Level Rise (RSLR) – increases north-west to south-east, on both short (20th Century) and long (late Holocene) timescales.
- Sediment supply – increases south to north.
- Marsh soil type – varies west (mineral, coarse-grain) to east (‘organic’, fine-grained).
- Tidal amplitudes around the UK – ranges from microtidal (Solent) to macrotidal (Morecambe Bay).

Having robust GHG data (chamber or Eddy Covariance) would enable a robust approach to development of further EFs. The C-SIDE project will inform further on the relative importance of these primary predictor variables, and could therefore in turn help to prioritise further GHG work to capture the largest differences first (e.g. concentrating on west vs east coast first to capture how soil type influences GHG emissions).

7 Priority work for a Tier 1 approach

Identified priority work needed for a Tier 1 approach to inclusion in the UK GHG inventory. If coastal wetlands are adopted they will become part of the wider effort towards using more accurate data, which would include a move to Tier 2/3.

1. For a new habitat to be included in the UK GHG inventory, decisions need to be made specifically defining the habitat for inclusion. Therefore, a definition of saltmarsh habitat needs to be developed, with detail as to what is and is not considered saltmarsh from an inventory point of view.

2. The UK's LULUCF inventory currently reports on land-based emissions above the mean high-water mark, and therefore some saltmarsh area will fall outside of this. However, according to IPCC guidelines (IPCC 2014) there are options for reporting emissions and removals from coastal wetlands even if these fall outside the defined land area of a country. Emissions and removals from these areas should be reported separately under the relevant land-use category, however the associated land areas should be excluded from the total area of the land-use category.

3. Definitions are needed for a 'transitional phase' – whilst restoration sites are in transition between their former land-use and intended habitat, as well as for successful land management change. For example, successful rewetting might require the establishment of recognisable saltmarsh plant communities over a defined percentage of the total area.

4. A base map of saltmarsh extent needs to be developed to enable tracking of change over time. We have identified a number of spatial data sources (presented in the accompanying excel file, outlined in appendix 2) to enable this.

5. Detail on saltmarsh condition and land use is also needed for the base map. Available spatial data sets require further evaluation, for example by overlaying with land-use maps and restoration/extraction site information.

6. Within restoration sites, detailed area data is needed for each habitat, to account for land-use change correctly and allow separate reporting. This information is not routinely included in the OMREG database information, and would need updating routinely as sites transition from their previous land-use into coastal habitat. A method for estimating extent over time using Google Earth imagery has been suggested (section 3.2).

7. A date at which vegetation has colonised 10% of a restoration site is needed to start accounting for soil carbon stock changes. The Google Earth method of assessing change over time may help here, depending on when suitable aerial imagery is available. Inferring colonisation rate from published work and aerial imagery may need to be extrapolated to sites with no data available.

8. For extraction activities to be assessed at a Tier 1 level, only material moved from vegetated habitats (predominantly seagrass) under anaerobic conditions, to aerobic conditions needs to be known. Sediment recharge – either through direct placement

on land for the creation of saltmarsh, or placed in the lower intertidal and left to dissipate – where the material has not impacted vegetated habitat (originates from the sea floor), could be proposed as an additional management activity and Tier 2 EFs developed.

8 Appendices

Appendix 1 – other recent, ongoing, or planned complimentary reports, projects, and papers

Kershaw, J., Gregg, R., Kmietowicz, E. Briefing: Blue Carbon. 2022. Climate Change Committee, UK.

- Presents the evidence of the potential for blue carbon to contribute to climate mitigation, and associated benefits such as climate adaptation.
- Makes recommendations including: better monitoring of change in the extent, condition, and functioning of marine and coastal ecosystems; increased protection and restoration; and increased recognition of the interaction between coastal ecosystems with wider catchments.

Mason, V.G., Wood, K.A., Jupe, L.L., Burden, A., Skov, M.W. 2022. Saltmarsh Blue Carbon in UK and NW Europe – evidence synthesis for a UK Saltmarsh Carbon Code. Report to the Natural Environment Investment Readiness Fund. UK Centre for Ecology & Hydrology, Bangor. 36pp

- A robust assessment of the evidence quantifying blue carbon in natural UK and NW European saltmarshes.
- Presents the first comprehensive estimate for restored sites.
- Highlights the need for more research on the influence of saltmarsh characteristics (e.g. pH, salinity, vegetation, sediment type) on the carbon and greenhouse gas fluxes of restored saltmarshes.

Hudson, R., Kenworthy, J. and Best, M. (eds) (2021). Saltmarsh Restoration Handbook: UK and Ireland. Environment Agency, Bristol, UK.

and

Gamble C., Debney, A., Glover, A., Bertelli, C., Green, B., Hendy, I., Lilley, R., Nuuttila, H., Potouroglou, M., Ragazzola, F., Unsworth, R. and Preston, J, (eds) (2021). Seagrass Restoration Handbook. Zoological Society of London, UK., London, UK.

- Both handbooks aim to lead to the creation of more habitat, leading to improved biodiversity & water quality, adaption to climate risks, and carbon benefits
- Includes chapters and information on:
  - Drivers for restoration
  - Pre- and post-restoration monitoring
  - Restoration methods

Manning, W.D., Scott, C.R and Leegwater. E. (eds) (2021). Restoring Estuarine and Coastal Habitats with Dredged Sediment: A Handbook. Environment Agency, Bristol, UK.

- Introduces the concept of beneficial use, the background on dredge and disposal activities, and links both to habitat restoration and ecosystem services
- Non-technical details on dredge and disposal methods, key considerations and proven and potential approaches

Introduces the concept of beneficial use, the background on dredge and disposal activities, and links both to habitat restoration and ecosystem services

- Describes the regulatory process specific to dredge-disposal activities, namely, assessing sediment quality and designating disposal sites.

R Gregg, J. L. Elias, I Alonso, I.E. Crosher and P Muto and M.D. Morecroft (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York. England only.

- Review of the scientific evidence base relating to carbon storage and sequestration by semi-natural habitats, in relation to their condition and/or management. This new report updates and expands previous work by Natural England on ‘Carbon storage by habitat’ published in 2012. Includes saltmarsh and seagrass.

Austin, W.E.N., Smeaton, C., Riegel, S., Ruranska, P. and Miller, L. 2021. Blue carbon stock in Scottish saltmarsh soils. Scottish Marine and Freshwater Science Vol 12 No 7. 10.7489/12372-1.

- Estimates of carbon held within the top 10cm and 15cm of Scottish saltmarsh soils.
- Builds upon the Scottish saltmarsh survey (Haynes, 2016) by integrating the mapped extent with field derived measurements.

Smeaton C, Hunt CA, Turrell WR and Austin WEN (2021) Marine Sedimentary Carbon Stocks of the United Kingdom’s Exclusive Economic Zone. Frontiers in Earth Science. 9: 593324. doi: 10.3389/feart.2021.59332.

- Improved estimates of carbon within the UKs marine sedimentary environments.

Green A.E., Unsworth R.K.F., Chadwick M.A., Jones P.J.S. 2021. Historical Analysis Exposes Catastrophic Seagrass Loss for the United Kingdom. Frontiers in Plant Science 12. doi: 10.3389/fpls.2021.629962.

- Documents 8,493 ha of recently mapped seagrass in the United Kingdom since 1998.

Armstrong, S., Hull, S., Pearson, Z., Wilson, R. and Kay, S., 2020. Estimating the Carbon Sink Potential of the Welsh Marine Environment. ABPmer report for NRW, Cardiff, 74p. Wales only.

- Most up-to-date and available spatial data layers for blue carbon habitats (including saltmarsh and seagrass) have been identified and combined

- Literature review of carbon storage and sequestration values
- C values have been calculated and put into context with terrestrial ('green carbon') rates, as well as Welsh CO_2 emissions.

O'Connor, J.J., Fest, B.J., Sievers, M., Swearer, S.E. 2020. Impacts of land management practices on blue carbon stocks and greenhouse gas fluxes in coastal ecosystems—A meta-analysis. Global Change Biology 26: 1354–1366. doi; 10.1111/gcb.14946.

- Broad search of the literature for papers concerning drivers of carbon sequestration and GHG emissions in coastal vegetated ecosystems.
- Synthesis of how management activities influence carbon stocks and GHG fluxes

Ruth Parker, Lisa Benson, Carolyn Graves, Silke Kröger, Rui Vieira. 2020. Carbon stocks and accumulation analysis for Secretary of State (SoS) region, Cefas Report for Defra project ME5439, 42 pp.

- Overview of carbon storage services provided by different habitats (including saltmarsh and seagrass), and how different activities influence this process. They identify a significant evidence gap has been a baseline understanding of present stock and fluxes and address this with the report through an extensive review of the relevant literature.

Burden, A., Garbutt, A., Evans, CD. 2019 Effect of restoration on saltmarsh carbon accumulation in Eastern England. Biology Letters. 15: 20180773. doi: 10.1098/rsbl.2018.0773

- Includes a model for predicting changes in carbon sequestration rate over time following saltmarsh restoration.
- This will be useful when developing Tier 2 EFs for saltmarsh condition.

Simon, R., Mitchell, A., Evans, C., Whitaker, J., Thomson, A., Keith, A. 2021. Greenhouse gas removal methods and their potential UK deployment. A report published for the Department for Business, Energy and Industrial Strategy by Element Energy and the UK Centre for Ecology and Hydrology. Published October 2021.

- Provides a comprehensive and up-to-date assessment of the costs and technical potential of GGR methods in the UK to inform policy decisions and the 2021 net-zero strategy.
- Integrated deployment scenarios are modelled using this assessment.
- Includes saltmarsh habitat restoration as a land-based GGR.

International Association of Dredging Companies (IADC) – Dredging for Sustainable Infrastructure book. (https://www.iadc-dredging.com/publication/dredging-for-sustainable-infrastructure/). Published 2018.

- Guidance to achieve dredging projects that fulfil their primary functional requirement, while at the same time delivering added value for nature and society as an inherent part of project development.
- Includes discussion on beneficial use as an alternative and encouraged sediment management option.

NERC C-SIDE project (Carbon Storage in Inter-tiDalEnvironments) https://www.c-side.org/. *Ongoing*.

- Has generated new data with the aim to develop predictive relationships between environmental drivers (sediment supply, tidal range, carbon source) and carbon stocks and accumulation to explain spatial and temporal patterns on a UK scale. A report on first order surficial carbon stock of UK saltmarshes will be available summer 2022.

A report by NOC for DAERA outlines blue carbon habitat restoration in Northern Ireland. *Not yet published*. Author(s): James Strong, Nils Piechaud and Catherine Wardell

- Calculates saltmarsh and seagrass extent in Northern Ireland, and provides associated shape files.
- Models habitat suitability and identifies likely distribution of species as well as suitable, though not currently colonised, habitat.

Project Seagrass (https://www.projectseagrass.org/). *Ongoing*.

- Environmental charity devoted to the conservation of seagrass ecosystems through education, influence, research and action.
- Linked to the Seagrass Ecosystem Research Group (SERG) – a collaboration between Swansea and Cardiff Universities.
- Seagrass distribution is a research theme of the group. Future updates on extent likely to involve this research group.

The UK's biggest seagrass restoration project: (https://www.swansea.ac.uk/press-office/news-events/news/2020/03/750000-seeds-planted-in-wales-inuks-biggest-seagrassrestoration-scheme-.php). *Ongoing*.

- Aims to restore 20,000 m^2 in Dale Bay, Pembrokeshire
- Planting over 750,000 seagrass seeds
- Currently working on upscaling seagrass restoration methods - including enhancing automation.

NERC ReSOW UK: Recovery of Seagrass for Ocean Wealth UK: (https://www.smmr.org.uk/funded-projects/restoration-of-seagrass-for-ocean-wealth-resow-uk/). *Ongoing.*

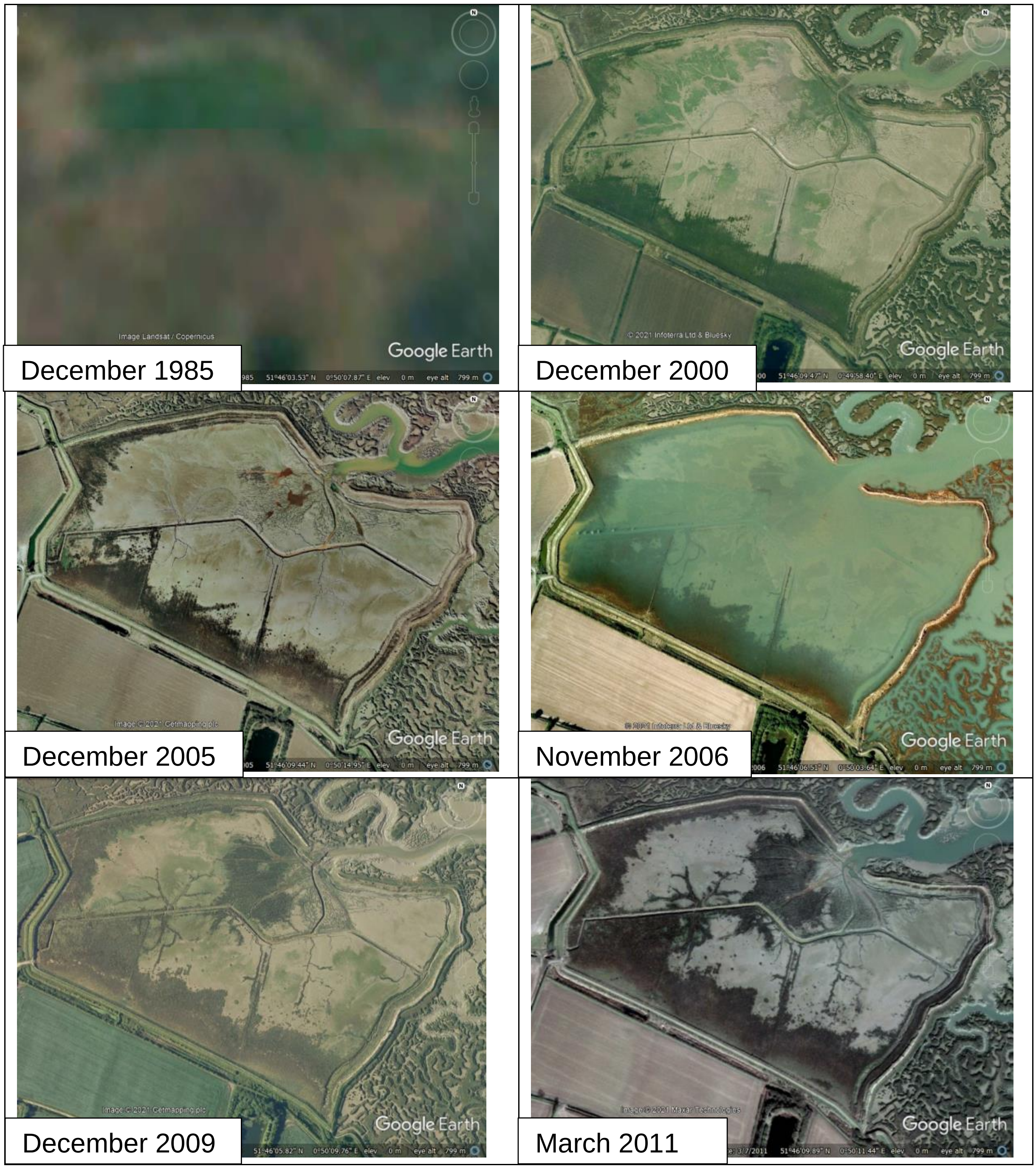
- Focuses on restoration of seagrass for sustainable social, environmental, and economic net gains for the UK.
- Proposes to provide new data on areal extent and soil stocks.

Appendix 2 – other files submitted as part of this report

Excel file	UKCEH NAEI Coastal wetlands_Data set information.xlsx
Description	Basic information and access information for all collated datasets covering: ▪ saltmarsh area ▪ saltmarsh change ▪ saltmarsh restoration ▪ extraction ▪ seagrass data (covers all data streams).

Excel file	UKCEH NAEI Coastal wetlands_extraction intersect with coast.xlsx
Description	MMO marine licences and applications point data (2002 – 2020) narrowed down by application of a 1km buffer of the coastline

Appendix 3 – Tracking change over time in restoration sites using Google Earth



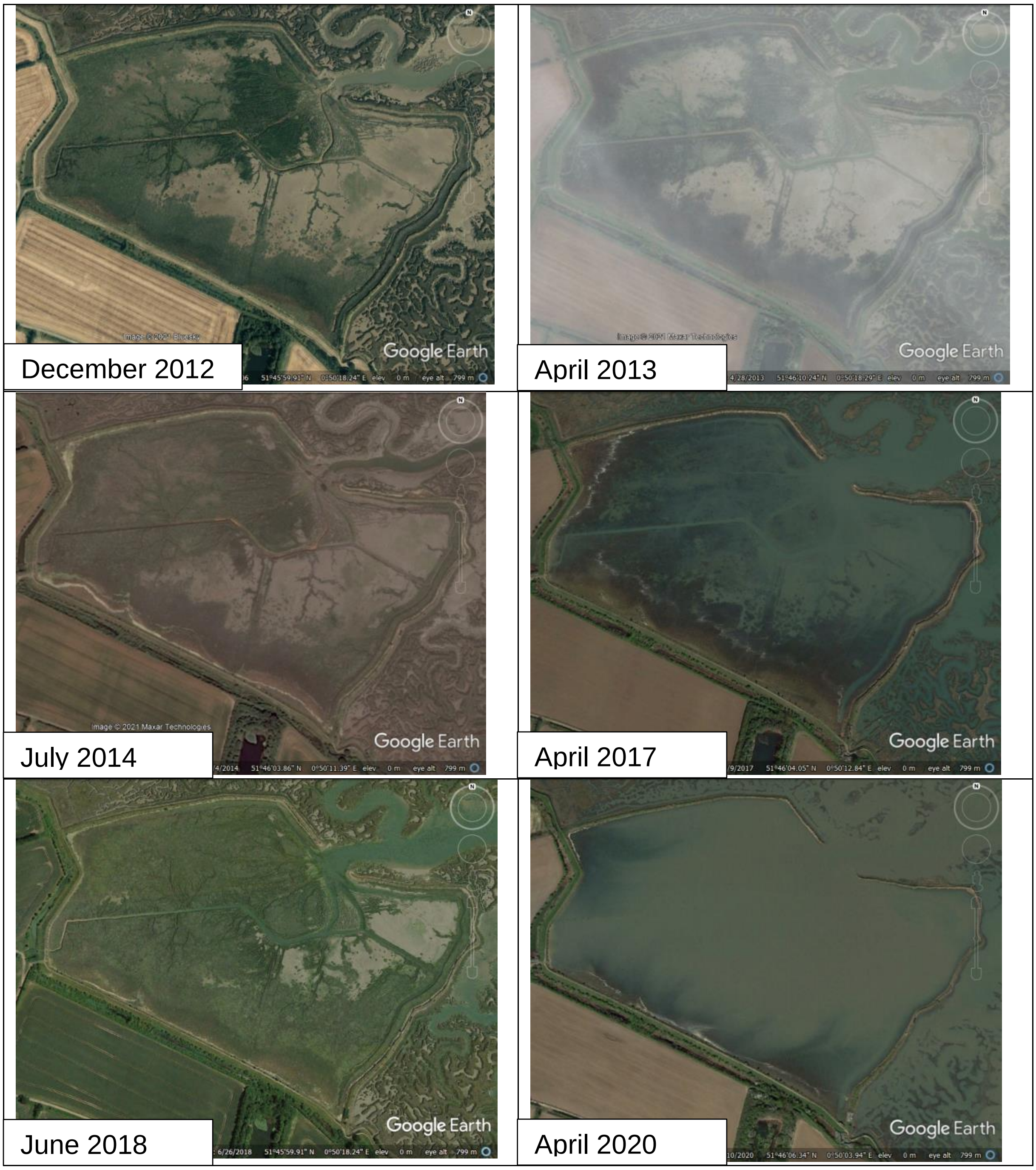


Figure A3 *Google Earth imagery available for the Tollesbury managed realignment site, Blackwater Estuary, Essex (51.7674, 0.8402). Restoration implemented on 04/08/1995. 21 ha site. OMREG online database describes habitat as mudflat and saltmarsh. First image before restoration, last image represents 25 years after restoration.*

Appendix 4 – Beneficial Use of Dredged Material activity data per year

Table A4 *Beneficial Use of Dredged Material activity data per year taken from individual project information within the OMREG online database (https://www.omreg.net/). Projects with no volume information: 1998 (1), 2001 (2), 2002 (1), 2007 (1), 2010 (1), 2017 (1). Also 1 project with no volume and the timeframe described as "to date".*

	Year	Range of years	Volume (m^3)
Anaerobic	1994		250,000
	1996		4,000
		2001 to present	2,000 per year (Total 42,000 to date)
	2015		800
		2014 - 2021	40,000
Anaerobic Total			**336,800**
Aerobic	1992		2,529
	1995		2,646
		1995 to present	600 per year (Total 15,600 to date)
	1997		22,000
	1998		45,500
		1998 to present	10,000 per year (Total 230,000 to date)
	1999		8,000
	2001		33,250
	2003		40,000
	2005		21,000
	2006		576,000
	2012		2,330
	2013		4,120
		2014 - 2021	40,000
Aerobic Total			**1,042,975**

Appendix 5 - Additional Maps

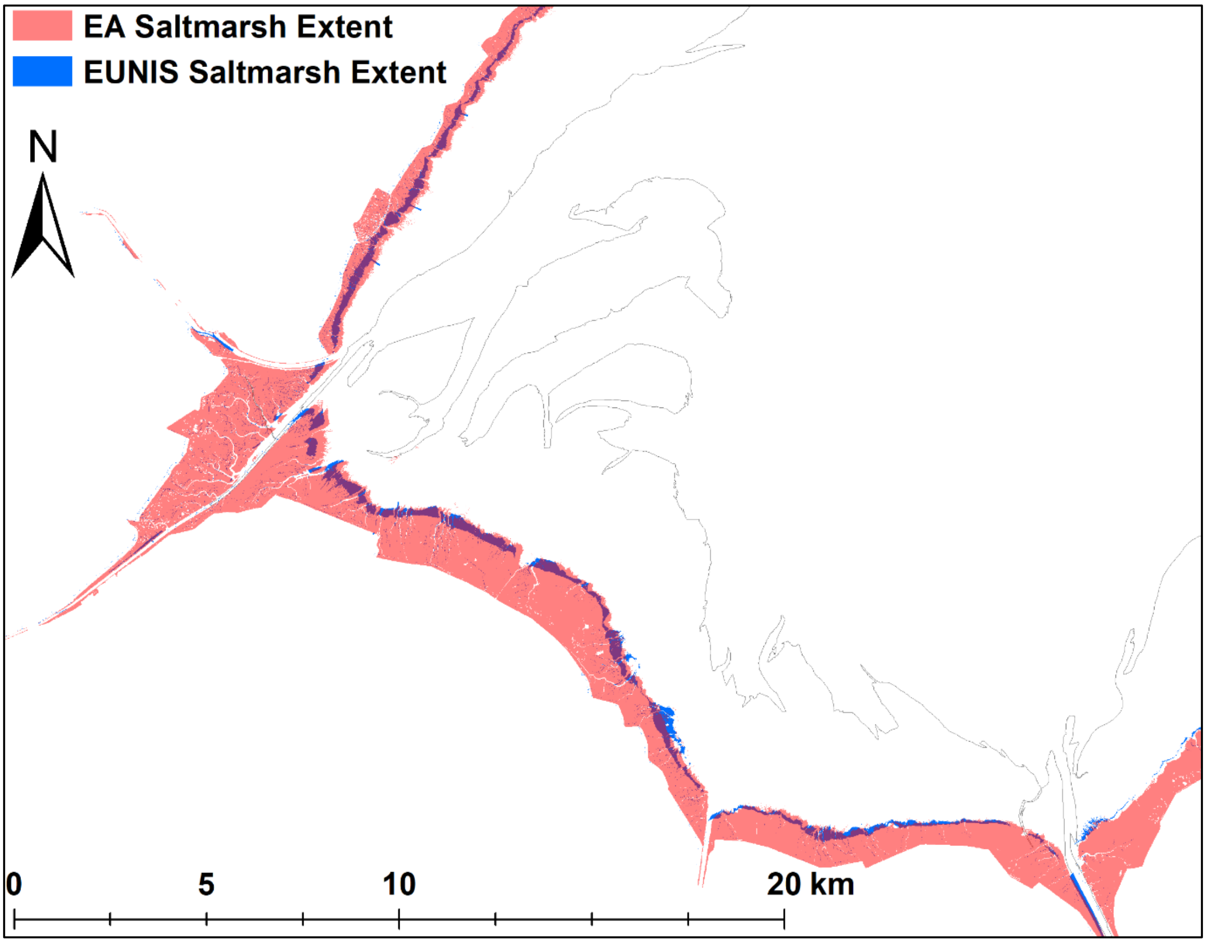


Figure A5.1 - *Estimated extent of saltmarsh in a section of The Wash, eastern England, showing overlap (in purple, 50% transparency applied to EA layer) between the EUNIS and EA datasets.*

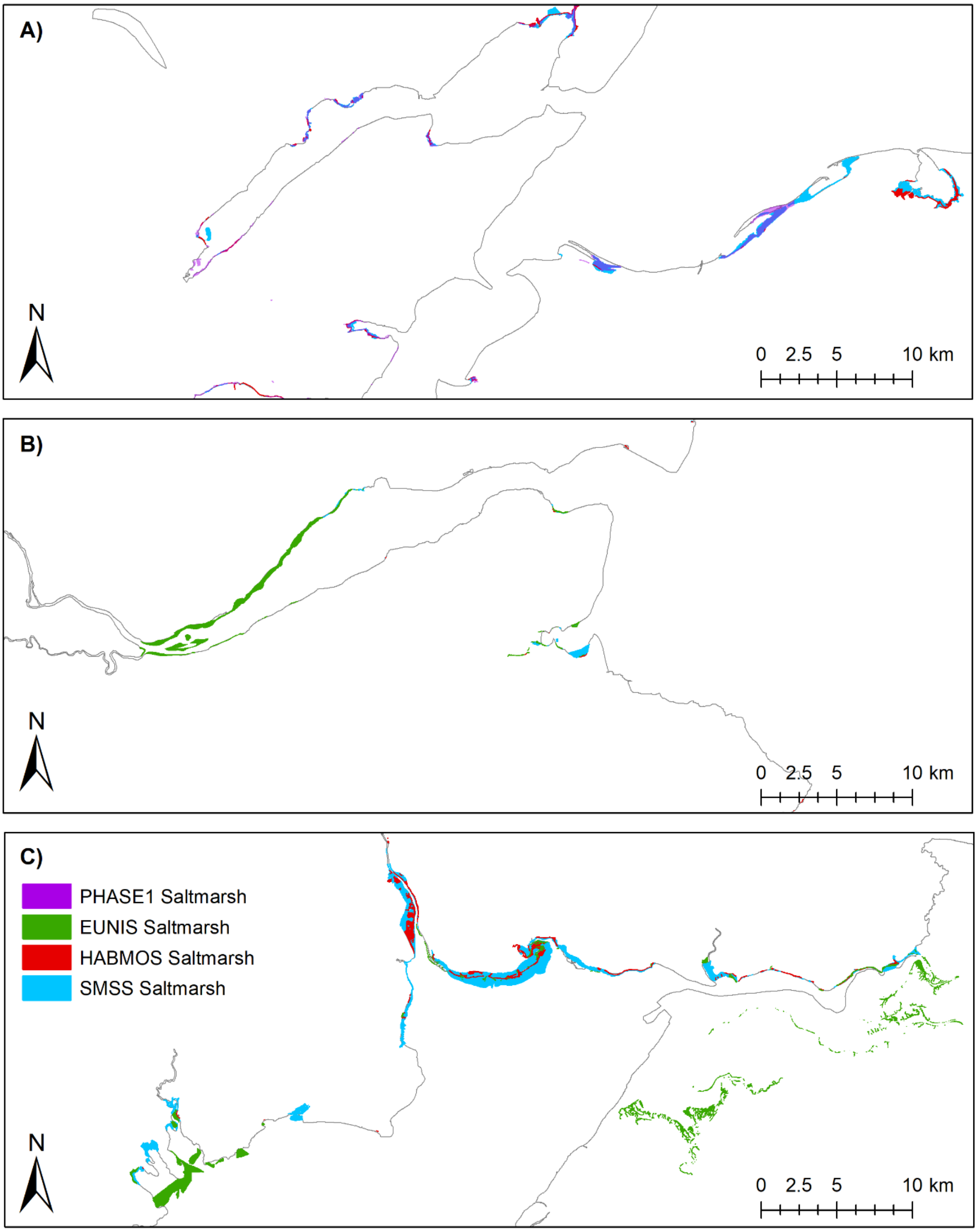


Figure A5.2 - *Saltmarsh extent in Scotland from the Nature Scot Saltmarsh Survey of Scotland (SMSS), Scottish Natural Heritage (HABMOS and Phase 1 Scotland), and the EUNIS habitat map, for A) the Moray Firth, B) the Firth of Tay, and C) Solway Firth.*

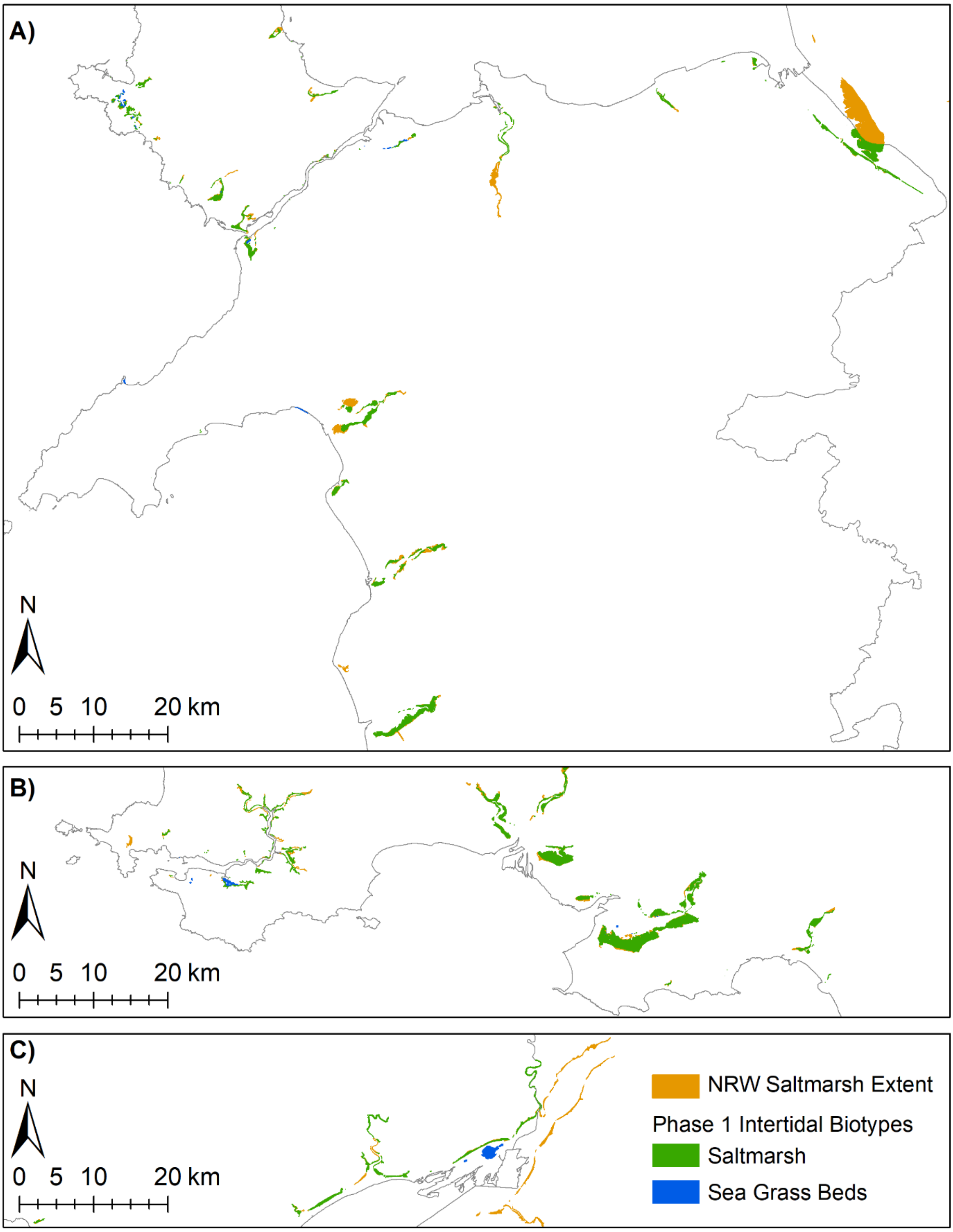


Figure A5.3 - *NRW estimated extent of saltmarsh and seagrass from the 1996 to 2005 Phase 1 Intertidal Biotypes layer, and saltmarsh from 2009 to 2017 (orange) for A) north and west, B) south-west, and C) south-east regions of Wales.*

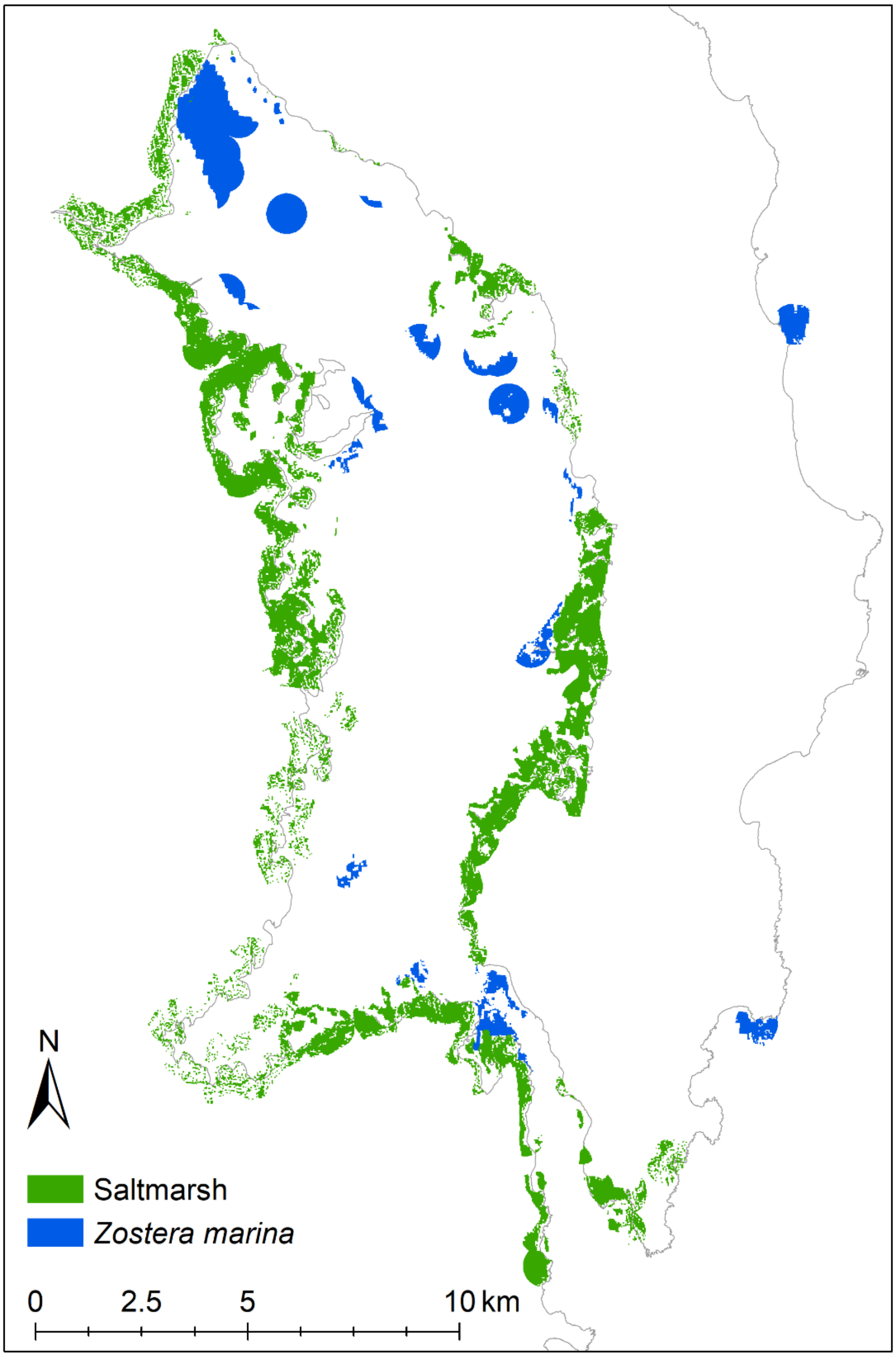


Figure A5.4 *- Estimated extent of saltmarsh and seagrass species in Strangford Lough, eastern Northern Ireland, from 1980 to 2020 provided by DAERA.*

Appendix 6 – Implementation requirements for chapter 4 of the Wetland Supplement.

Report to the Department of Energy and Climate Change, November 2016

Annette Burden, Chris Evans, Janet Moxley

NERC Centre for Ecology and Hydrology, Bangor and Edinburgh

A6.1 Introduction

The Wetland Supplement considers four activities which could affect the drainage status of Coastal Wetlands or result in land-use change: drainage to reclaim land from the sea; rewetting; management of mangrove forests; extraction of soil and sediment to create or maintain harbours and marinas, and to create ponds for aquaculture and salt recovery.

Coastal Wetlands are significant habitats for carbon accumulation that have the potential as important but previously neglected carbon sinks. The carbon sequestered in vegetated coastal ecosystems, such as mangroves, seagrass beds, and salt marshes, has been termed “Blue Carbon”. These ecosystems are highly productive and can continue to sequester and store carbon over long time periods.

Estimates of the carbon accumulation rate in Coastal Wetlands (calculated with sediment accretion rate and average carbon density of the sediment) are key to quantifying this potential. A recent study by Ouyang and Lee (2014), based on a meta-analysis, estimated the global mean carbon accumulation rate in salt marsh sediment as 245 ± 26 gC m^{-2} yr^{-1} (mean ± SE) with a higher European estimate of 312 ± 51 gC m^{-2} yr^{-1}. This carbon accumulation rate ranks first amongst all Coastal Wetlands and forested terrestrial ecosystems.

The combination of high capacity for sequestration but low observed total carbon stock in salt marshes of the UK is a legacy of past management approaches to these habitats which has resulted in significantly reduced areal extent due, in most, to land claim for agricultural use. The remaining salt marsh area is at risk of erosion and further decrease in extent due to pressures from sea level rise and coastal flooding, and from ‘coastal squeeze’ whereby intertidal habitats are unable to migrate inland due to the presence of sea-defences (Adaptation Sub-Committee, 2013).

Drainage and reclamation of low lying coastal land exposes previously anaerobic soil to oxygen, resulting in the release of CO_2. The Wetland Supplement states that emissions from drainage of coast soils remain constant until a steady state carbon contents comparable with similar naturally drained soils are reached, and gives Tier 1 emission factors for these losses. As emissions from soils continue after the year of drainage, activity data will need to include areas drained prior to 1990, as well as drainage since then, to enable reporting.

Some coastal realignment involving rewetting coastal areas has occurred in the UK. The Environment Agency is undertaking a number of realignment projects which aim to reduce flood risk, increase biodiversity, and promote resilience to climate change. In order to report on potential emissions, activity data are therefore needed on the extent of such schemes. All schemes have happened since 1990, so would be included in inventory reporting. There are also sites where sea defences have been breached due to storms (accidental breaching). Area data for these are also needed, including any that took place prior to 1990 where rewetting continues to affect emissions.

The areal extent of coastal realignment is currently limited, but could increase if further coast realignment is undertaken as an adaption to climate change or as part of flood protection schemes. In England there are long-term plans to realign 10% of the coastline by 2030, rising to 15% by 2060 (Adaptation Sub-Committee, 2013). The Wetland Supplement requires emissions and removals from changes in biomass, dead organic matter and soil carbon stocks to be assessed and gives Tier 1 emission factors. Similar activities may occur in the OTs and CDs, in which case activity data will be needed.

Mangrove forests are not present in the UK or in any of the OTs and CDs covered by LULUCF reporting. However, mangroves do occur in a number of the other OTs, primarily in the Caribbean (Table A6.1), amounting to a total area of around 320 km^2. The majority of this (73%) occurs in the Turks and Caicos Islands, and is believed to be in a stable (and largely protected) condition (FAO, 2007). The Cayman Islands hold a further 24%, and the stock here is believed to have decreased by around 5% since 1990. The British Virgin Islands contain around 2% of the total area, and the mangrove area here is thought to have decreased by 15% since 1990. Other countries hold small areas of mangrove (< 100 ha), although the small area in Bermuda is also thought to have decreased since 1990.

Table A6. 1*. Reported mangrove areas in UK Overseas Territories (FAO, 2007).*

Overseas Territory	Mangrove area (ha)	Change since 1990
Anguilla	90	None recorded
Bermuda	15	-2 ha
British Indian Ocean Territory	Negligible	None recorded
British Virgin Islands	587	-90 ha
Cayman Islands	7,830	-400 ha
Montserrat	5	None recorded
Turks and Caicos Islands	23,600	None recorded

Seagrass beds are present in UK territorial waters, but estimates of the areal extent of this habitat are sparse, with detailed data limited to only a few sites. Seagrass beds also occur in some of the OTs and CDs, notably in the Turks and Caicos Islands where seagrass meadows are critical for food security (Baker et al, 2015). The global total area is estimated to be 177,000 km^2, however these habitats are declining and it has been suggested that more than 51,000 km^2 has been lost in the last 127 years, with the rate of decline accelerating over the past eighty years (Waycott et al, 2009). Decline is attributed to both direct (from coastal development and dredging) and indirect (declining water quality) impacts. Seagrass meadows are categorised as a habitat in decline in OSPAR region II (Greater North Sea – The North-East Atlantic) and in the UK are identified as a Feature of Conservation Importance (FOCI). Reporting on emissions and removals from seagrass beds (around the UK or in the CDs and OTs) would require much more comprehensive information on their extent, condition and associated carbon stocks. It is also worth noting that, because seagrass beds are permanently inundated, any emissions or removals associated with them occur outside the land area currently used for UK emissions reporting, and that activities affecting them in general do not conform to the general definitions of drainage or re-wetting. On the other hand, their inclusion in the 2013 IPCC Wetland Supplement (IPCC, 2014) implies that they may nevertheless represent significant areas for CO_2 emissions and removals.

Extraction activities, particularly in relation to harbours, occur in both the UK and those OTs and CDs which report LULUCF activities. Tier 1 methodology assumes that if the dredged material is applied to land, all carbon in extracted material is oxidised to CO_2 in the year of extraction. Information on the mass of material extracted and applied to land would therefore be needed to allow reporting; however no central organisation collates such information, so absolute figures remain hard to estimate. Most dredged material is disposed of at sea, but in recent years there have been moves to reduce marine disposal and increase the deposition of material on land. Although the emissions from this activity are likely to be considerably less than those resulting from peat extraction on a per-area basis, further assessment of activity data is needed to understand the likely importance of this activity for the LULUCF inventory. If the Tier 1 assumption that oxidation of organic matter in the dredged material – and any changes in biomass carbon stocks – occur in the same year as dredging, data would only be needed from 1990 onwards. However this assumption may not be valid in all cases (for example where terrestrially excavated material is used to create new saltmarsh habitat).

Coastal aquaculture in the UK uses cages rather than constructed ponds and therefore does not involve extraction. Aquaculture ponds on Coastal Wetlands are not known to occur in the UK or the OTs and CDs which report LULUCF activities. Similarly, although there have historically been small salt pans in the UK, none are believed to be currently operating in the UK or in the CDs and OTs which report LULUCF activity.

A6.2 Area extents

A6.2.1 Current area estimates

The extent of saltmarsh habitat in the UK is currently estimated to be between 40,000 and 45,000ha (Table A6.2). There is no current UK level estimate of seagrass bed extent, although it is known that they occur to a much lesser extent. Estimates for other coastal habitats such as sand dunes and sandy beaches and machair dune grassland do exist (Table A6.3). Whilst the 2013 IPCC Wetland Supplement does not include emission guidance for these habitat types, it is worth noting that sand dune ecosystems contain dune slack wetlands which can be carbon rich.

Table A6. 2*. Area estimates for saltmarsh in the UK.*

Reference	Estimate (ha)	Notes
Burd, F. 1989	44,370	Total area of saltmarsh in Great Britain based on data collected between 1981 and 1988.
Environment Agency 2011	40,522	The extent of saltmarsh in England and Wales: 2006 – 2009
Jones et al, 2011 (NEA)	44,512	Salt marsh extent in UK
Countryside Survey 2007 estimates[1]	43,600	Total for UK
Haynes, 2016 (SNH report)	7,704	Total area of saltmarsh recorded and mapped between 2010 and 2012

[1]estimates of 'Littoral Sediment' broad habitat. In LCM2007 littoral sediment is mapped as two classes: 'Saltmarsh' and 'Littoral sediment'. Saltmarsh is a Priority Habitat and of sufficient extent and spectral distinction to be mapped consistently. The remaining 'Littoral Sediment' is mapped spectrally, although there may be some confusion with the 'Supra-littoral sediment' class.

Table A6. 3. *Area estimates for other coastal habitats in the UK*

Reference	Habitat	Estimate	Units
Burrows et al, 2014	Seagrass beds in Scotland	15.9	km^2
Burrows et al, 2014	Kelp habitat in Scotland	2,155	km^2
Jones et al, 2011	Sand dune	71,569	ha
Jones et al, 2011	Machair	19,698	ha
Jones et al, 2011	Shingle (vegetated)	5,852	ha
Jones et al, 2011	Sea cliffs[1]	4,554	km^2
Jones et al, 2011	Coastal lagoons	5,184	ha

[1]incomplete data

A6.2.2 Previous salt marsh extent

The current extent of saltmarsh habitat in the UK is considerably less than in the past. Historically, large areas of salt marsh were drained and cut off from the tide by sea defences to increase the area that could be used for agriculture. More recently, salt marsh habitat has been claimed for port development, and sea-level rise also poses a threat through coastal squeeze – where the natural landward migration of salt marshes is restricted by sea defences (Blackwell et al., 2004; Adaptation Sub-Committee, 2013).

There are many estimates of the extent of salt marsh habitat loss. French (1997) estimated that globally, 25% of intertidal estuarine habitat has been lost due to land reclamation, and more recently Barbier (2011) estimated that 50% of the world's salt marshes have been degraded or lost mainly due to habitat conversion (or destruction). On an annual basis the loss rate has been estimated at between 1 and 2% (Nottage and Robertson, 2005; Duarte et al., 2008). Based on the estimates in Table A6.2, the UK has experienced a higher annual loss rate, of around 4%, between 1988 and 2009. However, the differences in methodology between Burd (1989) and the Environment Agency (2011) survey make it difficult to verify this.

Within an estuary, salt marsh area reflects an equilibrium between erosion and accretion, so it is difficult to accurately estimate the extent of salt marsh at a particular time in the past. Here, we used The Soil Survey of England and Wales (Avery, 1980) to estimate the original extent before land claim started. All soil sub-group categories described as having formed on marine alluvium were assumed to have once been intertidal habitat (Figure A6.1). This approach suggests that around 4% (rising to 4.3% when including estimated soil types within unsurveyed areas, such as those in coastal urban areas) of the total area of England and Wales was previously intertidal habitat, compared with just 0.2% today. This equates to a loss of around 652,500 hectares of intertidal habitat, i.e. 94% of the original wetland extent. The largest areas of former intertidal habitat, as indicated by this assessment, are around the Wash, Humber, Severn and Thames estuaries (Figure A6.2).

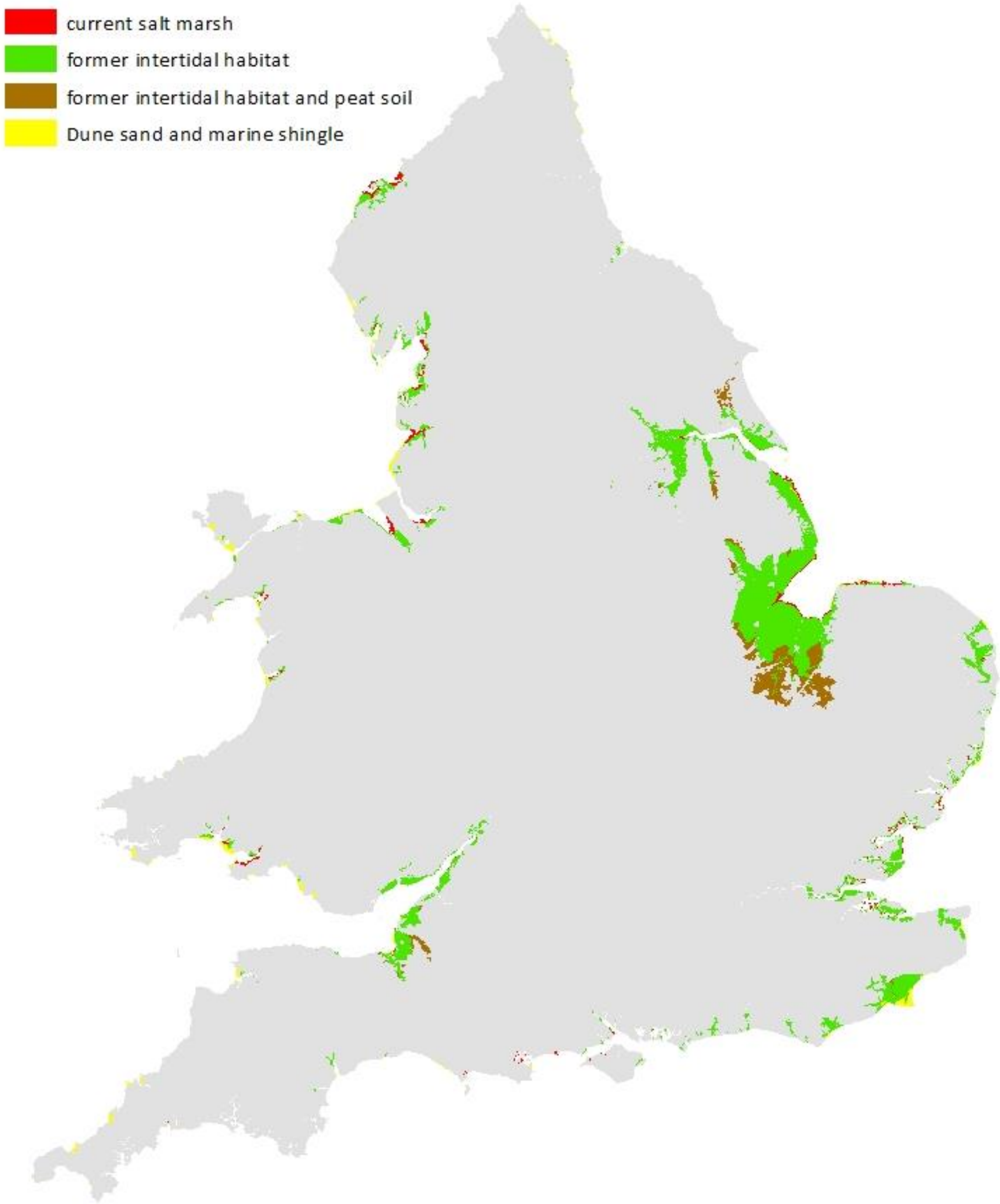


Figure A6. 1. *Estimated area of former intertidal habitat taken from The Soil Survey of England and Wales (Avery, 1980). Red = current salt marsh, Green = former intertidal habitat, Brown = former intertidal habitat over peat soil, Yellow = sand dune and marine shingle.*

We then used the Land Cover Map 2007 (LCM2007 - Morton, 2011) to map the current land use of former and current intertidal and salt marsh soil areas. The 23 LCM2007 land classes were aggregated into 10 broader classes (Table A6.4). The most common current land use is arable land, occupying 68% of the total former intertidal wetland area. Improved and semi-natural grassland occupy 17% and 5%

respectively. It can be assumed that both woodland aggregate land classes, arable, both grassland classes and built-up areas have all been drained.

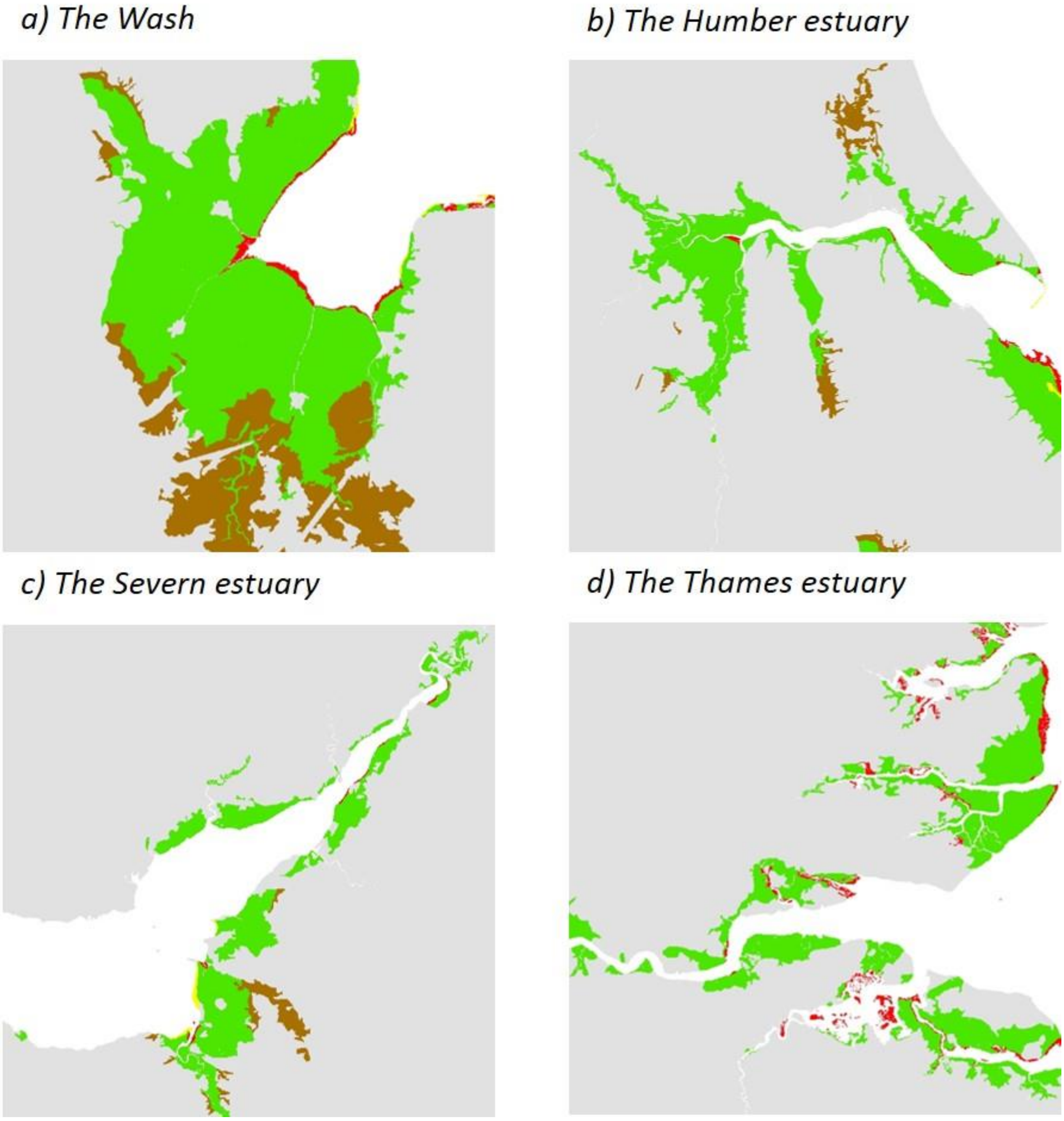


Figure A6. 2. *Illustrative examples of former intertidal area for four regions. a) – c) at 1:500,000 scale, d) 1:300,000 scale. Colour scheme as in Figure A6.1.*

Table A6. 4. *Current land use of salt marsh soil area in England and Wales according to LCM2007.*

Aggregate class	**ha**	**%**
Broadleaf woodland	6,628	1.1%
Coniferous woodland	968	0.2%
Arable	414,259	67.5%
Improved grassland	101,923	16.6%
Semi-natural grassland	27,756	4.5%
Mountain, heath, bog	1,305	0.2%
Saltwater	1,139	0.2%
Freshwater	3,460	0.6%
Coastal	34,342	5.6%
Built up areas, gardens	21,449	3.5%
Unknown	131	<0.1%
Total	**613,359**	

The same mapping exercise was not possible for Scotland, as such no comments can be made as to the potential loss of intertidal habitat. However, a recent report commissioned by Scottish Natural Heritage (Haynes, 2016) surveyed and mapped all known saltmarshes larger than 3 hectares across the Scottish mainland and islands (between 2010 and 2012). This estimated the current area to be 7,704 hectares, with 76% dominated by saltmarsh vegetation. Swamp vegetation dominated a further 12%, and 13% was mapped with other vegetation or land cover types. Condition assessments of the saltmarsh were carried out during the survey to determine if they were in ‘favourable condition’, as defined by the EU Habitats Directive (European Commission, 1992). Based on this assessment 67% of saltmarsh failed, the main reasons for which were attributed to the presence of built structures (for example, embankments) and lack of natural landward transition habitats. The reasons for these saltmarshes being in unfavourable condition may well include damage due to drainage. However, there is no estimate of the area extent this may effect.

A6.2.3 Rewetted salt marsh area estimates

Since the early 1990s, managed realignment – the landward retreat of coastal defences and subsequent tidal inundation of reclaimed land – has increasingly been used across Europe to mitigate against historic and on-going losses of salt marsh habitat. It is also undertaken to enable government compliance with the European Union Habitats Directive (C.E.G., 1992) which states there should be 'no further net loss of coastal marsh' (UK Biodiversity Group, 1999). Table A6.5 details the rewetted salt marsh sites in the UK. A total area of 2,572 hectares has been created since 1991 either by making a breach in the seawall (with or without prior land raising) or by regulated tidal exchange – where sluice gates or culverts, for example, are used to create new intertidal habitat behind permanent sea defence structures.

There have also been many accidental breachings of sea walls during storm events (for example in the storms of 1897 and 1953 along the South East coast of the UK). However many of these accidental breaches are historic (i.e. prior to the 1990 baseline year for reporting) and there is no central record of the areas involved or exact dates when breachings occurred. However, Burden et al (2013) estimated that managed realignment sites could take approximately 100 years to accumulate a soil carbon pool equivalent to natural marshes, at a rate of 0.92 t C ha^{-1} yr^{-1}. This could mean that sites affected by historic (pre-1990) breaches are still contributing towards emission reductions, and should therefore be considered when reporting.

Some restoration of former saltmarsh starts with raising the land surface level before re-connecting to the tide. If the material used is derived from marine dredging, this would also fall within the remit of the dredging activities described in the following section. However not all material used in such schemes is obtained in this way. An example of this is the current partnership between Crossrail and RSPB on the Wallasea Island Wild Coast project in Essex (www.rspb.org.uk/wallaseawildcoast). This project aims to transform 670 acres of farmland back to intertidal habitat, approximately 400 years after reclamation. Over three million tonnes of excavated material from Crossrail's underground tunnelling in central London have been used to raise the surface level of Wallasea Island by an average of 1.5m (www.crossrail.co.uk/construction/tunnelling/excavated-material). This material will be of a different composition to marine dredged material commonly used for land reclamation projects, and therefore any carbon emissions may also be different to other managed realignment and land reclamation projects. The current Wetland Supplement guidance does not include guidance on such activities.

Table A6. 5. *Area estimates for rewetted salt marsh sites in the UK (ABPmer, 2014). Year vegetated estimate taken as 3 years after creation. Method B = Breach(es) made in seawall, BLR = Breach(es) in seawall with prior land raising or sediment recharge, RTE = Regulated Tidal Exchange.*

Method	Year rewetted	Year vegetated (over 10%)	Size of site (ha)
B	1991	1994	0.8
	1994	1997	4.8
	1995	1998	59
	1997	2000	7.2
	2000	2003	13.4
	2001	2004	25.9
	2002	2005	162
	2003	2006	105
	2004	2007	7
	2006	2009	447
	2007	2010	8.2
	2008	2011	200
	2010	2013	48
	2011	2014	13
	2013	2016	46.5
	2014	2017	475
	2015	2018	22
			1,644.8
BLR	2000	2003	16.5
	2006	2009	133
	2015	2018	165
			314.5
RTE	1993	1996	9
	1995	1998	11.6
	1999	2002	29
	2000	2003	31.25
	2004	2007	10.8
	2006	2009	90
	2007	2010	14
	2009	2012	38.4
	2010	2013	4.5
	2011	2014	44
	2013	2016	306
			588.55[1]
			2,547.85[2]

[1]does not include a 10 ha site as date created unknown
[2]does not include 13.9 ha of B/RTE land as date and/or method not known

A6.2.4 Dredging activity estimates

The IPCC guidelines state that significant emissions will result from dredging activities when material is removed from saturated (water-logged) conditions and deposited in unsaturated (aerobic) conditions, for example when associated with creation of new areas of land. Therefore, only activities that result in dredged material being placed on land are considered here.

In most ports and harbours, dredging is a necessary activity to maintain navigable depths and for flood control. Material is dredged and relocated for disposal elsewhere. Between 20 and 40 million tonnes of material are dredged from English and Welsh ports, harbours and their approach channels every year (www.ukmarinesac.org.uk, 2001) and the majority of material is disposed of at sea. There are around 150 licensed disposal sites, however the amount of material deposited in this way is reducing in favour of options that derive a beneficial use such as in construction and saltmarsh restoration schemes.

Limited data are available on dredging activities that result in material being placed on land, and no central body/organisation collates such information. From internet searches of large dredging companies operating in the UK, only one had available data detailing amounts and year of activity (Table A6.6), however this cannot be assumed to be a complete list of activities.

Assuming this dredged material has an average density of 1,300 kg m^{-3} (www.ukmarinesac.org.uk/ activities/ports/ph5.htm), the activity detailed equates to 1.8 million tonnes of material, although from the limited explanation of the projects, not all of this material can be assumed to be aerobic.

Table A6. 6. *Dredging projects in the UK resulting in material being deposited on land (www.boskalis.com). CD = Chart Datum.*

Year	Amount of material m^3	Material type	Project type	Notes

2011	195,000	Shingle	Beach replenishment	All material aerobic
2011	80,000	Shingle	Beach replenishment	All material aerobic
2008-10	500,000	No information	Land reclamation	Area raised from -12m CD to +6m CD. Not all material aerobic
2011	246,000	Sand	Land reclamation	All material aerobic
2007	300,000	Sand	Beach replenishment	All material aerobic
2009-10	100,000	sand/silt/clay	Land reclamation	All material aerobic. Not all material used

A6.3 Emission estimates

A6.3.1 Drainage to reclaim land from the sea.

As detailed in section A1.2.20 there has been extensive drainage of saltmarsh habitat in the UK. Around 93% of the land area of former and current intertidal and salt marsh soil in England and Wales can be considered drained due to its current land use. However, this drainage is historic and therefore the soil carbon stock could be considered to have reached a new steady state (i.e. no net emissions or removals), and therefore reporting is not needed. If further drainage occurs, data needs for biomass, dead organic matter and soil carbon are the same as outlined for rewetting in, although estimates of extent of vegetation are not needed.

A6.3.2 Rewetting, revegetation and creation

Sufficient data are available on coastal realignment (and associated rewetting) in the UK to support a Tier 1 approach to estimate carbon stock changes, and CO_2 emissions and removals, associated with rewetting, revegetation and creation activities relating to tidal marshes. An overview of data needed for tier 1 is shown in Table A6.8, together with the data needs to move towards a tier 2 approach.

There are currently insufficient data regarding areal extents of seagrass beds to enable a Tier 1 approach to be implemented.

<u>Biomass</u>

A Tier 1 approach assumes no changes in biomass carbon stocks to occur as a result of rewetting. Therefore the biomass carbon stock change would be zero (Table A6.7).

Tier 2 estimates follows the same guidance as ‘Grassland remaining Grassland’ outlined in Volume 4, chapter 6 of the 2006 IPCC guidelines. Where significant changes in grassland management or disturbance are experienced, development of Tier 2 or 3 approaches are encouraged. In the UK managed realignment converts –

in the most part – agricultural land into salt marsh, which constitutes a significant change. There is therefore a need to capture more detailed data at these coastal realignment sites for the UK to move towards Tier 2 reporting.

Specific estimates on increase in carbon stocks due to biomass growth, and decrease due to biomass losses would be needed. The guidelines assume the carbon stock in biomass reaches a new steady state within a year of the land-use change, however this could be challenged at a Tier 2 or above level. Only above-ground biomass stock data would be needed as expansion factors for below-ground to above-ground biomass ratios are given (for different climatic zones including temperate) to estimate the below-ground proportion.

To calculate the change in carbon stocks, the change in biomass would then be multiplied by the carbon content of the dry biomass. Chapter 6 of the 2006 IPCC guidelines gives default carbon content values for woody and herbaceous biomass, so an estimate of the proportion of each would be needed.

Dead Organic Matter (DOM)

Tier 1 methodology assumes that dead wood and litter stocks do not change as a result of rewetting so there is no need to estimate carbon stock changes. Therefore the dead organic matter carbon stock change would be zero (Table A6.7).

As is the case for biomass carbon stock changes (section A6.3.2.10), Tier 2 estimates follow the same guidance as 'Grassland remaining Grassland' outlined in Volume 4, chapter 6 of the 2006 IPCC guidelines, and again where significant changes in grassland management or disturbance are experienced, development of Tier 2 or 3 approaches are encouraged.

For Tier 2 reporting each of the DOM pools (dead wood and litter) needs to be addressed separately. Data from which to estimate the average annual transfer of biomass into, and decay out of, the two pools due to processes and disturbances would be needed as no default factors exist. To convert the net change in DOM stocks to carbon stocks either the carbon fraction for each pool would also need to be known, or the defaults provided could be used.

Soil Carbon

A CO_2 emission factor of zero for soil carbon is applied at Tier 1 where no vegetation has been established, or where reestablishment is expected to occur by recolonization. An emission factor should only be applied once plant cover extends over at least 10% of the overall area. It is only at Tier 2 where it is advised to reassess this assumption.

At Tier 1, using the area data for managed realignment schemes from Table A6.5 (section A6.1.20) and the default emission factor given for tidal marsh in the Wetland Supplement (-0.91 tonnes C ha^{-1} yr^{-1}), the annual net removal of CO_2 from the atmosphere (i.e. sequestration into soil carbon stocks) as of 2015 is estimated to be -1395 tonnes C yr^{-1} (Table A6.7). For each managed realignment site, it is assumed that at least 10% of the overall area had become vegetated within 3 years. This was inferred from data on vegetation re-colonisation at one managed realignment site in Essex, East coast of the UK (Wolters, 2008) and may not be representative of all sites. Speed of colonisation is likely to be variable between sites as it is highly dependent on the starting elevation, amongst other factors. Some low lying sites will need a number of years of accreting sediment before the tidal elevation is suitable for plants to establish.

It is also worth noting that the current long-term plans in England to realign 10% of the coastline by 2030, rising to 15% by 2060 (Adaptation Sub-Committee, 2013) would likely give another 14,000 tonnes C yr^{-1} of mitigation, rising to 21,000 tonnes C yr^{-1}

For Tier 2 reporting, the IPCC guidelines suggest that country-specific emission factors could be applied which disaggregate soil type (organic and mineral) and climate. It is also advised to reassess the assumption that there is no change in the soil carbon stock until the re-saturated soil has been colonised with plants.

Non-CO_2 emissions - CH_4

For re-wetting that results in salinities greater than 18ppt, zero CH_4 emissions are assumed at all reporting tiers. As all coastal realignment in the UK produces saline conditions, CH_4 emissions are considered to be zero for all newly created sites.

Table A6. 7. *Annual Tier 1 estimates for soil carbon uptake by rewetted UK salt marsh as of 2015. Units = tonnes C yr-1. CI = 95% confidence interval.*

	Tier 1 estimate	Upper CI	Lower CI
Biomass	0	0	0
Dead organic matter	0	0	0
Soil carbon	-1,395.4	-1073.4	-1,686.7
Total	**-1,395.4**	**-1073.4**	**-1,686.7**

Table A6. 8. *Activity data needed for Tier 1 and 2 emission estimates arising from rewetting, revegetation and creation of mangroves, tidal marshes and seagrass meadows.*

	Tier 1	Tier 2

Biomass	No data needed. Assumes no change in biomass stock as a result of rewetting.	▪ Annual above-ground increase due to biomass growth ▪ Annual above-ground decrease due to biomass losses ▪ Carbon content of dry biomass ▪ Proportion of woody and herbaceous biomass
Dead Organic Matter (DOM)	No data needed. Assumes no change in DOM as a result of rewetting	▪ Two DOM pools to address separately. ▪ Average annual transfer of biomass into and decay out of each pool due to processes and disturbances ▪ Carbon fraction of each pool
Soil Carbon	Estimate of when 10% of the overall area is colonised by vegetation	UK-specific emission factor disaggregating organic and mineral soil type
Non-CO_2 emissions	Assumes no non-CO_2 emissions as a result of rewetting if the salinity is greater than 18ppt	▪ Assumes no non-CO_2 emissions as a result of rewetting if salinity is greater than 18ppt ▪ UK-specific CH_4 emission factor based on water salinity if less than 18 ppt

A6.3.3 Extraction of soil and sediment used to raise elevation of land and enable port, harbour and marina development

There are currently insufficient data regarding extraction activities to enable a Tier 1 approach to be implemented. Information is needed regarding excavation and dredging associated with raising the elevation of land, and enabling port, harbour and marina construction and filling. Sudden increases in these activities have the potential to cause large emissions given the assumption that all carbon will be emitted as CO_2 during the same year as extraction. Area extents of all activities are needed along with data outlined in Table A6.9.

One potential problem with estimating emissions due to land reclamation is that the volume of material used does not necessarily correspond to the area associated with the project, as it will also depend on how much the surface level of the land is being raised by, as well as the proportion of the material that is above sea level (i.e. subject to aerobic decomposition). For countries like the UK, where land reclamation is currently a relatively small activity, calculating emissions based on tonnes of material presumed to be aerobic may be more practical.

Table A6. 9. *Activity data needed for Tier 1 and 2 emission estimates arising from extraction of soil and sediment used to raise elevation of land and enable port, harbour and marina development.*

	Tier 1	Tier 2
Biomass	▪ Change assumed to be zero for Coastal Wetlands without perennial biomass or trees ▪ If perennial biomass or trees present, stock after conversion presumed to be zero	▪ Above-ground biomass before activity ▪ Above-ground biomass after activity ▪ UK-specific ratio of below-ground to above-ground ▪ Carbon fraction of dry matter ▪ Evaluation of assumption all oxidised in same year as activity
Dead Organic Matter (DOM)	No data needed. Changes assumed to be zero	▪ Evaluation of assumption all oxidised in same year as activity ▪ UK-specific dead organic matter carbon stocks for Coastal Wetlands with perennial biomass
Soil Carbon	No data needed. Defaults provided.	▪ Knowledge of soil type (organic or mineral) ▪ Evaluation of 1m extraction depth assumption ▪ UK-specific soil carbon stock to disaggregate soil type ▪ UK-specific emission factor to disaggregate soil type

A6.4 Areas that may require further methodological development

The area estimates for rewetted saltmarsh habitat in the UK (Table A6.5) are taken as the area between the old sea defence that has been breached (or within which a regulated tidal structure has been installed) and the new landward border, which is often a constructed wall. However, this quoted area is not always all coastal habitat. It can include areas of transitional grassland and agricultural land that lie in front of the new wall and are not flooded by the tide. For example, at the Medmerry (West Sussex,) 300 ha Regulated Tidal Exchange site, only 183 ha is flooded by the tide while the surrounding areas remain under arable and grazing land (ABPmer, in prep).

With this in mind, it is estimated that only 45% of managed realignment sites are saltmarsh habitat, with a further 21% occupied by mudflat (Table A6.3). Thus an assumption that all land affected by managed realignment reverts to saltmarsh could potentially lead to an inaccurate emission estimate, as each habitat will have a different emission factor. To account for rewetted Coastal Wetlands correctly, detailed area data would be needed for each habitat within managed realignment sites, with each being reported on separately.

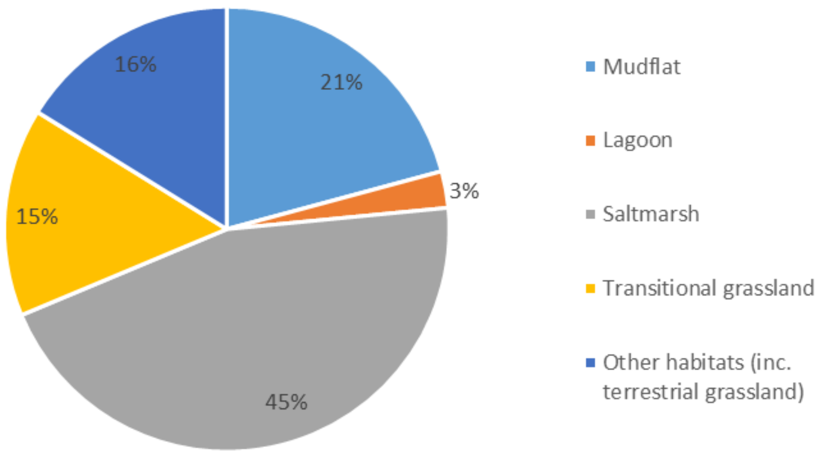


Figure A6. 3. *Estimate of habitat areas within UK managed realignment sites.*

When applying the Wetland Supplement guidelines, and particular when using default, or country-specific emission estimate values, consideration should be given to regional differences that may occur. Salt marshes on fine sediments are predominant on the East Coast of the UK, whilst more sandy sediments are typical of the West Coast. This – along with North to South differences in species ranges – tends to mean that species and community composition differ, as well as soil type. This may result in marked differences between actual emissions, suggesting a possible need for region- or soil-type specific emission factors when moving to a more detailed (Tier 2 or 3) approach to accounting.

It is also recommended by the Wetland Supplement that each country clearly define the concept of coastal land. This sea- and landward limit should then be applied consistently over time. This issue is particularly relevant to seagrass beds as they occur in shallow water, predominantly below the low tide mark. If the current seaward limit to the area of the UK is taken as the mean high water mark, this would need to be changed in order to account for seagrass beds.

A6.4.1 Coastal habitats not considered by the Wetland Supplement

The 2013 IPCC Wetland Supplement does not include any guidance for dune wetlands. Sand dunes cover 71,000 ha in the UK (Jones et al. 2011), although the extent of dune wetland within that area is smaller. Dune wetlands have a high carbon sequestration rate, 73 ± 26 g C m^{-2} yr^{-1} (Jones et al. 2008), and are estimated to store around 347,000 t C in the UK, of which 25,000 t (7%) is in above-ground biomass, 76,000 t (22%) is in below-ground biomass, and 245,000 t (71%) is in soils (Beaumont et al. 2014). Threats to dune wetlands include habitat conversion/appropriation for e.g. tourism infrastructure or housing, golf courses, and disruption of groundwater tables through modification of drainage or changes in land use such as forestry practices on adjacent land (Jones et al. 2011). Recent survey data show that since 1990 there has been a 30% decline in the extent of dune wetlands in England (Stratford et al. 2013). However, changes in extent in Wales, Scotland, NI and overseas territories are not known.

A6.5 Conclusions

Coastal Wetland are thought to have been subject to comparatively high levels of historic modification by drainage and land-use change, which is likely to have contributed to past CO_2 emissions, but which may now present opportunities to sequester CO_2 through activities such as rewetting, land-use change and managed coastal realignment.

Extensive drainage of Coastal Wetlands has occurred in the UK. Of the 4% of land in England and Wales that could be classed as current or former Coastal Wetland, only 0.2% remains as intact salt marsh and therefore, in general, it is not thought of as an important habitat for climate regulation. However, due to its high rate of potential carbon accumulation, and the potential area that could be considered suitable for restoration, the mitigation potential of 'Blue Carbon' in the UK could be reconsidered. Of the previous extent in England and Wales, 89% (over 540,000 hectares) is now used for agriculture or under improved or semi-natural grassland. Some of this area could potentially be reconnected to the tide (rewetted) to create more intertidal habitat. With increased storminess and sea level rise, it may become economically unsustainable to maintain all current sea defences. An analysis of the gain of intertidal land, the sea defence this would provide, and the increased potential for carbon sequestration, versus the future production value of the agricultural land that could be subject to realignment, would need to be completed.

All managed realignment in the UK has happened since 1990, and therefore comprehensive data are available on rewetting for UK salt marshes to the point where Tier 1 level estimates can already be made. Detailed information regarding past drainage of salt marsh is less easy to find as the majority of land reclamation for agricultural use took place in the 1700s and 1800s. Current estimates can only be made by overlaying soil and land-use maps.

In order to implement reporting on Coastal Wetlands, reliable and complete estimates of salt marsh and sea grass extent would be needed. A consistent survey methodology for each habitat would also provide accurate estimates of trends and extent over time, and allow changes due to land-use change to be accounted for. Development of UK-specific soil carbon emission factors would also allow more detailed Tier 2 level reporting.

In general available data for the OTs and CDs are either not available, or are less detailed than for the UK. However some of the OTs do incorporate large areas of Coastal Wetland, including mangrove swamp and seagrass beds, and in some OTs these areas are believed to be in decline.

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