THE UNITED KINGDOM'S BLUE CARBON INVENTORY:

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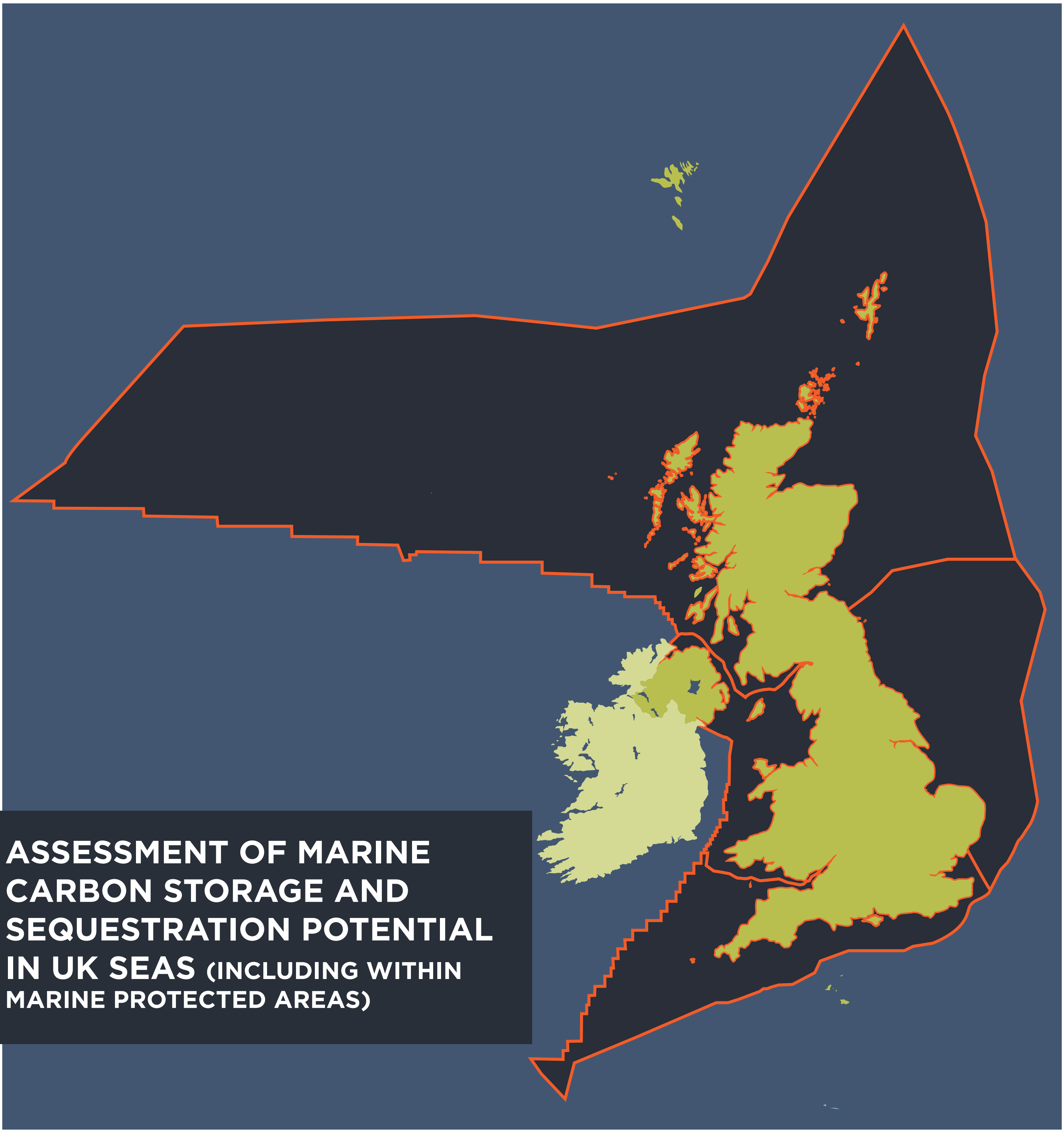

ASSESSMENT OF MARINE CARBON STORAGE AND SEQUESTRATION POTENTIAL IN UK SEAS (INCLUDING WITHIN MARINE PROTECTED AREAS)

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The United Kingdom's Blue Carbon Inventory:

Assessment of Marine Carbon Storage and Sequestration Potential in UK Seas (Including Within Marine Protected Areas)

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Assessment of Marine Carbon Storage and Sequestration Potential in UK Seas (Including Within Marine Protected Areas): Executive Summary for Policymakers

This report was commissioned by WWF, The Wildlife Trusts and the RSPB to assess the extent, scale, distribution and potential of the current blue carbon sinks in the region of water in the UK's Exclusive Economic Zone (EEZ), the UK continental shelf (including Rockall) and the Territorial Seas of the Isle of Man ('UK seas'). This report summarises the four regional reports of the UK's Blue Carbon Assessment: (1) the English North Sea Region (Burrows *et al*., 2021), (2) the English Channel and Western Approaches Region (Burrows *et al.,* 2024a), (3) the Irish Sea and Welsh Coast Region, which includes coastlines in Northern Ireland, England and Wales (Burrows *et al.,* 2024b) and (4) the Scotland Region (Burrows *et al.,* 2024c). The objectives of this synthesis report were to summarise the series of reports in order to provide (1) information on the current extent and distribution of blue carbon habitats, including seabed sediments and coastal vegetated habitats, (2) estimates of the quantity of carbon currently stored across the four assessment regions, (3) assessments of the average net sequestration rate (g $C/m^2/yr$), and (4) the potential net total sequestration (g to Mt C/yr) of blue carbon habitats and their contribution to differences among regions and their areas designated for protection. This report also aims to compare the similarities and differences between regions, including the quantity of blue carbon within existing marine protected areas. The focus of this series of reports has been on stores and accumulations of organic carbon (OC) as particulate material rather than inorganic carbon (IC), given the likely net production of CO_2 through the production of IC as shell material.

Carbon store densities and rates of production and storage have been combined with measures of habitat area to give estimates of total carbon stored in blue carbon habitats and their associated sediment stores. The results are intended to inform management decisions and identify opportunities to enhance the seabed and its carbon sequestration potential. This evidence will contribute to exploration of the potential of the UK Marine Protected Area (MPA) network to help mitigate against the effects of climate change.

The extents of blue carbon habitats for UK seas were derived from available sources, including the EUNIS level 3 combined map from the Joint Nature Conservation Committee (JNCC), Natural England Marine Habitats and Species Open Data, and recently published estimates of OC and IC in long-term stores in surface sediments (Smeaton *et al*., 2021a).

Main Findings

• This report covers the UK's Exclusive Economic Zone (EEZ), the UK continental shelf and the Territorial Seas of the Isle of Man. Together, the UK's EEZ and UK continental shelf (including Rockall) cover an area of **885,000 km²** [1](Joint Nature Conservation Committee, 2024), while the Territorial Waters of the Isle of Man cover an area of **3,970 km²**.

• The Scotland Region covers an area of **617,000** km² (including **462,000 km²** of the UK's EEZ), representing 70% of the UK's sea area; the English North Sea Region covers an area of **114,000 km²**, representing 13% of the total; the English Channel and Western Approaches Region covers an area of **111,000 km²**, representing 13% of the total; and the Irish Sea and Welsh Coast Region, including the Welsh coastline, covers an area of **43,000 km²**, representing 5% of the total[1].

• **Carbon in long-term stores** is locked away from atmospheric circulation for significant time periods (generally over 100 years). In total, **244 Mt of organic carbon (OC)**[2] is estimated to be **in long-term stores** across UK seas, with 98.3% (240 Mt; Table 1 and Table 3) of that total

[1] Values are rounded to the nearest 1,000 km².
[2] Rounded to the nearest million tonnes (Mt).

stored in the top 10 cm of seabed sediments. Carbon in sediments below 10 cm is largely unquantified and relatively old, and has therefore not been included in this assessment. 1.7% (4.1 Mt) of total OC is found in coastal vegetated blue carbon habitats (kelp beds, intertidal macroalgae, saltmarshes and seagrass beds) but only **2.6 Mt is stores long-term in saltmarsh and seagrass sediments**, the rest being living material largely in kelp beds. Although coastal vegetated blue carbon habitats represent only 1.0% of the total area of UK seas, they contain 1.7% of the total OC stores, and account for 3.8% of annual accumulated OC in those stores.

• Sources cited in the regional reports indicate that coastal saltmarshes in the UK contain 60% of OC in long-term stores in coastal vegetated blue carbon habitats (**526 km^2, 2.4 Mt OC**; see Table 4) and 1.0% of all seabed sediment OC, most of which is found in extensive saltmarshes in England and Wales.

• Known seagrass beds hold approximately 8% of OC stored in coastal vegetated blue carbon habitats and 0.10% of total sediment OC in long-term stores. Improved mapping is needed for a better understanding of the extent and distribution of seagrass across the UK (66 km^2, **139,000 t OC**; see Table 4).

• **Carbon in short-term stores** is that which is temporarily fixed or removed from atmospheric circulation for less significant time periods (e.g., in living biomass). Living kelp biomass in the UK accounts for 35% of OC in coastal vegetated blue carbon habitats, approximately 0.6% of total OC stores. Kelp contains 35% of coastal vegetated blue carbon and 0.03% of total OC (7,776 km^2, **1.4 Mt OC**; see Table 4). Kelp forests are most extensive on the west coast of Scotland where subtidal rocky areas provide suitable habitat for kelps to flourish.

• Seabed sediments are by far the most important habitat for carbon storage in the UK's seas, due to their extent (**706,000 km^2 [mapped areas only]**, **240 Mt OC**; see Table 4). It is important to note that this analysis considers only surficial sediments, which account for the top 10 cm of the seabed, and therefore represent only a fraction of the overall carbon stored in the full thickness of these sediments.

• Areas designated for marine protection – that is, Marine Protected Areas (MPAs), Marine Conservation Zones (MCZs), Special Protection Areas (SPAs), Marine Nature Reserves (MNRs) and Special Areas of Conservation (SACs) – across the UK's EEZ and continental shelf cover **338,000 km^2** (Joint Nature Conservation Committee, 2024[3]). Mapped areas of stored carbon extend only as far as the UK EEZ boundary, so only those designated areas within the EEZ were considered (see Table 1), with 322,000km^2 accounting for overlapping designations, and excluding the Hatton Bank MPA and coastal sites of special scientific interest (SSSIs). This represents 38% of the total area of the UK's EEZ and continental shelf (890,000 km^2). The long-term stores of carbon in MPAs with mapped carbon information are estimated to contain **105 Mt of OC**, accounting for 43% of the total OC in long-term stores, and **534 Mt of inorganic carbon (IC)**, accounting for 45% of the total IC stored. Values for carbon inside protected areas in the four regional reports do not account for overlapping designations and are considerably larger.

• Offshore MCZs, MPAs and SACs contain the largest proportion of OC and IC in long-term stores, but inshore, littoral MPAs, and notably the smaller marine portions of SSSIs, have the highest densities and rates of OC accumulation per unit area in their coastal muds, saltmarshes and seagrass beds. MPAs with predominantly rocky habitats have less OC in long-term stores and reduced OC accumulation rates relative to sediment habitats, but do support extensive kelp beds that contribute carbon to neighbouring areas of sediment.

• Rates of accumulation of OC in seafloor sediments around the UK are highly variable and largely uncertain. OC accumulation is dominated by that in mud and sand/mud seabed sediments, with the fastest rates seen in fjordic sediments in Scotland's sea lochs (50–200 g C/m^2/yr). Using the rates of sedimentation measured in such places and applied to all coastal muddy sediments, it is estimated that **13.5 Mt of OC are added annually to sediment stores**

[3] Rounded to the nearest 1,000 km^2.

(see Table 3). Other studies (see Sections 4.1.1 and 4.1.2) suggest that offshore mud habitats, especially in the North Sea, may accumulate at far slower rates (1–5 g C/m^2/yr). Using these much slower rates, total accumulation of OC across the UK's EEZ may be as low as **424,000 tC** annually (see Table 5). Actual OC accumulation rates in offshore sediments across the whole of the UK's EEZ most likely lie between these two extremes.

• Coastal vegetated blue carbon habitats (saltmarshes and seagrass beds) store **271,000 tC/yr** (see Table 4, 'Influx'); this is equivalent to 2.9% of the higher value of carbon storage (13.5 Mt C/yr) but 64% of the lower value (424,000 t C/yr), with saltmarsh soils accounting for 97% of the accumulation among coastal vegetated blue carbon habitat stores.

• Growth and reproduction of algae and plants (primary producers), with subsequent losses and transport to stores in the seabed, are the main mechanism for removal of CO_2 by the marine ecosystem. Unlike rates of plant growth, the proportion of detritus from primary producers that reaches storage over climatically relevant time periods is poorly understood and potentially highly variable, despite recent research. A value of 10% of annual primary productivity (g C/m^2/yr) was adopted as the fraction of OC that is transported from standing in long-term stores and stored within seabed sediments; this value is typically used in ecosystem models. Based on this assumption, the quantity (10% of the total) of **production of particulate organic carbon** (**POC**) **by algae and plants** assumed to reach sediment stores is dominated by phytoplankton (**7.2 Mt C/yr**, termed 'Outflux' in Table 3). It is estimated that **286,000 t C/yr** (see Table 4) are added as POC from coastal vegetated blue carbon habitats (kelp, intertidal macroalgae, seagrass and saltmarshes) for potential storage in seabed sediments (including the soils of seagrass beds and saltmarshes). Out of all the coastal vegetated blue carbon habitats in the UK, kelp contributes most to POC (**258,000 t C/yr**), followed by saltmarshes (**7,300 t C/yr**), seagrass beds (**1,200 t C/yr**) and intertidal macroalgae (**19,000 t C/yr**). These values are broadly consistent with quantities of OC added to seafloor habitats using higher rates of OC accumulation in mud habitats, but greatly exceed estimates using lower rates.

• Saltmarshes add far more OC per year to their soils (**205,000 t C/yr**, see Table 4: All UK, 'Influx') than saltmarsh plants produce as detritus (7,300 t C/yr, see Table 4 'Outflux'). Most of the OC stored in saltmarshes is of terrestrial origin.

• Although the analysis here is based on the best information available at the time of writing, it must be understood that values presented for sizes of carbon stores and rates of accumulation are built on critical assumptions and caveats. Carbon in seabed sediments has been considered here for only the top 10 cm of marine deposits. This has been driven by the sampling of such sediments using surface grabs and very shallow sediment cores. The full depth of coastal sediments has not been assessed, and represents a much larger store of carbon. However, carbon in surface sediments is the most recently deposited and most vulnerable to the effects of physical disturbance. Information on rates of seabed sediment accumulation is much more limited, especially compared with such rates in coastal vegetated habitats, which have been the focus of much recent research. Both differences in the methods adopted for spatial calculations and missing information for parts of the regions may have introduced discrepancies in some of the values presented across the reports. Details of the methods used are given in each section.

• Integrating the understanding of carbon storage provided by marine habitats into decisions relating to marine management would improve the protection provided for these habitats and enhance their capacity to act as carbon sinks. In some cases, where blue carbon habitat is covered by an existing MPA designation, management measures that have the specific objective of protecting or restoring habitats which contain such carbon in long-term stores can be considered alongside primary biodiversity considerations as potential nature-based solutions (NBS) to mitigate the impacts of climate change.

• The most widespread threat to OC in long-term stores is physical disturbance of the seabed (surface abrasion and subsurface penetration and disturbance), which arises from a range of human and natural activities. The predominant anthropogenic source of physical disturbance is demersal fishing activities, which occur throughout the seas of the UK, but deployment of moorings and installation of offshore energy platforms and associated cables and pipelines also disturb the seabed.

• The impacts of climate change, specifically ocean acidification caused by increased CO_2 concentrations, are likely to have mixed effects on blue carbon capture and storage, with a negative impact on calcareous organisms (i.e., those that build carbonate skeletons) and carbonate sediments, but potentially benefit for photosynthetic species (e.g., kelp and other macroalgae).

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Acronyms and Abbreviations

ASSI	Area of Special Scientific Interest
BGS	British Geological Survey
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CVBC	Coastal vegetated blue carbon (habitat)
DAERA	Department of Agriculture, Environment and Rural Affairs
Defra	Department of Environment, Food and Rural Affairs
DIC	Dissolved inorganic carbon
DOC	Dissolved organic carbon
EA	Environment Agency
ECWA	English Channel and Western Approaches
EEZ	Exclusive Economic Zone
EUNIS	European Nature Information System
GBIF	Global Biodiversity Information Facility
GIS	Geographic information system
HCRP	Habitat Compensation and Restoration Programmes(s)
HPMA	Highly Protected Marine Area
IC	Inorganic carbon
ICES	International Council for the Exploration of the Sea
JNCC	Joint Nature Conservation Committee
MCZ	Marine Conservation Zone
MMO	Marine Management Organisation
MNR	Marine Nature Reserve
MPA	Marine protected area (general term for an area designated for protection); Marine Protected Area (a designated area in Scotland)
Mt	Million tonnes
NBN	National Biodiversity Network
NBS	Nature-based solutions
NE	Natural England
OBIS	Ocean Biodiversity Information System
OC	Organic carbon
PIC	Particulate inorganic carbon
POC	Particulate organic carbon
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest

TWTs	The Wildlife Trusts
UK	United Kingdom
UKCEH	UK Centre for Ecology & Hydrology
USA	United States of America
WWF	World Wildlife Fund

1 Introduction to the UK Blue Carbon Assessment

1.1 Background and rationale

This series of reports, commissioned by The Wildlife Trusts, the WWF and the RSPB, uses a habitat-orientated approach to assess marine carbon stores in UK seas, including such stores within marine protected areas[4]. 'Blue carbon' habitats are broadly considered here to be all those habitats that make significant contributions to the accumulation and storage of carbon (beyond the narrow definition of coastal vegetated habitats, i.e., saltmarshes, seagrasses and kelp forests, and mangroves in tropical regions). Such habitats present in the area are identified and reviewed with regard to their potential to capture and store carbon, focusing on the ecology of the key carbon-fixing and habitat-forming species, the dynamics of physical habitats, and quantitative estimates of carbon in long-term stores and of rates of carbon fluxes. The report considers exports from and imports to these habitats, and threats to long-term stores and fluxes of carbon, as well as the potential for restoring damaged or degraded habitats to improve carbon storage and sequestration. Habitat reviews have identified sources of information on known and predicted habitat extents and combined these into maps and associated GIS data files. This collected information is used to synthesise an ecosystem-scale carbon inventory of the key rates and ultimate sequestration capacity of each habitat.

This project has been carried out in distinct phases divided into regional seas, including the English North Sea Region (Burrows *et al.*, 2021), the English Channel and Western Approaches Region (Burrows *et al.*, 2024a), the Irish Sea and Welsh Coast Region (Burrows *et al.*, 2024b) and the Scotland Region (Burrows *et al.*, 2024c), culminating in the present report with the combination and synthesis of a UK-scale assessment. The resulting synthesis and assessment of carbon sequestration capacity aims to establish a baseline that will guide conservation and restoration efforts in the future.

Assessment of carbon sequestration and storage follows the sequence of combining estimates of area with habitat-specific rates of production, loss, import and export of carbon, and thence area-specific rates of sequestration, to give area-integrated estimates of the total amount of carbon locked away by biological activity in the coastal and marine zones of the UK. The present report is a synthesis of previous publications, which follow that of successful and widely used audits of carbon storage and sequestration processes, primarily the review of Scotland's blue carbon in long-term stores (Burrows *et al.*, 2014) and more recently the four regional reports which outlined carbon stores within the English North Sea Region (Burrows *et al.,* 2021), the English Channel and Western Approaches Region (Burrows *et al.,* 2024a), the Irish Sea and Welsh Coast Region (Burrows *et al.,* 2024b) and the Scotland Region (Burrows *et al.,* 2024c). For the regional reports, further partitioning of blue carbon in long-term stores and processes among MPAs inform the role of designated areas in protecting the capacity of coastal and offshore habitats to sequester carbon (as was done in the earlier report for Scotland: Burrows *et al*., 2017).

Primary information on the area and location of blue carbon habitats and associated sediment stores has been compiled from existing habitat maps, building on the data sources used in recent reviews of blue carbon by Natural England (Gregg *et al*., 2021) and Defra/Cefas (Parker *et al*., 2021) for England and Wales, incorporating the addition of primary data from archived sediment samples to improve the spatial resolution of sediment types, and the contribution of MPAs to the protection of carbon in long-term stores (Flavell *et al.*, 2020). Where observed data do not give the extent of habitats or patterns of carbon stored directly, estimates of carbon density and total amounts stored have been made from the predictions of statistical models of habitat suitability (Burrows *et al*., 2018; Kettle *et al*., 2020; Wheater *et al.*, 2020) and carbon types stored (Diesing *et al*., 2017; Smeaton *et al*., 2021a), based on relationships between known records and data layers for physical and biological drivers of species distributions and

[4] 'Marine Protected Area' is a specific designation in Scotland; 'marine protected area' is a general term for areas designated for protection.

carbon stored by sediments. Such estimates have been reported for the whole region and for focal areas, including MPAs. Although they have lower confidence levels than direct observations, such models highlight where natural processes result in hotspots for carbon storage, and where these hotspots may be especially susceptible to remobilisation and oxidation through anthropogenic activity, such as trawling and renewable energy developments, as well as to natural processes such as wave-driven sediment resuspension and river-derived plumes.

Carbon budgets and carbon stores for each blue carbon habitat described in this report use the available information on extent and biomass. Net sequestration capacity (g C/m^2/yr) of each habitat depends on the balance of processes of net production as reported in the relevant habitat review sections, which has been synthesised for each regional assessment as well as the cumulative analysis.

The occurrence and extent of blue carbon habitats and sediment stores in marine protected areas, including Nature Conservation Marine Protected Areas (NCMPAs) in Scotland, Marine Conservation Zones (MCZs) in England, Wales and Northern Ireland, Marine Nature Reserves (MNRs) in the Isle of Man, Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) in all devolved administrations, as well as Sites of Special Scientific Interest with marine portions (SSSIs) in devolved administrations and Areas of Special Scientific Interest (ASSIs) in Northern Ireland (see Figure 1), are evaluated and combined across the four Regions covered by the regional reports.

1.2 Project objectives

The main purpose of this project is to ascertain and assess the extent, scale, distribution and potential of the current blue carbon habitats in the UK (saltmarsh, kelp forests, intertidal seaweeds, seagrass beds, biogenic reefs and seabed sediments). The aims of the project were as follows:

- to review the current extent and distribution of each blue carbon habitat
- to estimate the quantity of carbon currently stored within each blue carbon habitat
- to establish the average net sequestration rate (in g C/m^2/yr) of each blue carbon habitat
- to estimate the potential net sequestration (in g C/yr) of each blue carbon habitat
- to estimate the quantity of carbon stored in and potential sequestration rates of marine protected areas in the UK and Isle of Man (NCMPAs, MCZs, MNRs, SPAs, SACs, SSSIs and ASSIs)
- to further develop analytical methodology and approaches that can be refined on an ongoing basis.

The results are intended to inform management decisions and identify opportunities to enhance seabed biodiversity and its carbon sequestration potential. Evidence of this nature will contribute to exploration of the potential of the UK's MPAs to help to mitigate the effects of climate change by capturing and/or storing carbon.

Maps of major carbon stores and the associated blue carbon habitats are presented throughout this report, including maps of sediment organic carbon (OC) density (see Figure 2), sediment depth (see Figure 3), seabed habitats (see Figure 4) and coastal vegetated blue carbon habitats (see Figures 8–12). Regional-scale details of habitats and local-scale case studies are not included here, but can be found in the separate regional reports.

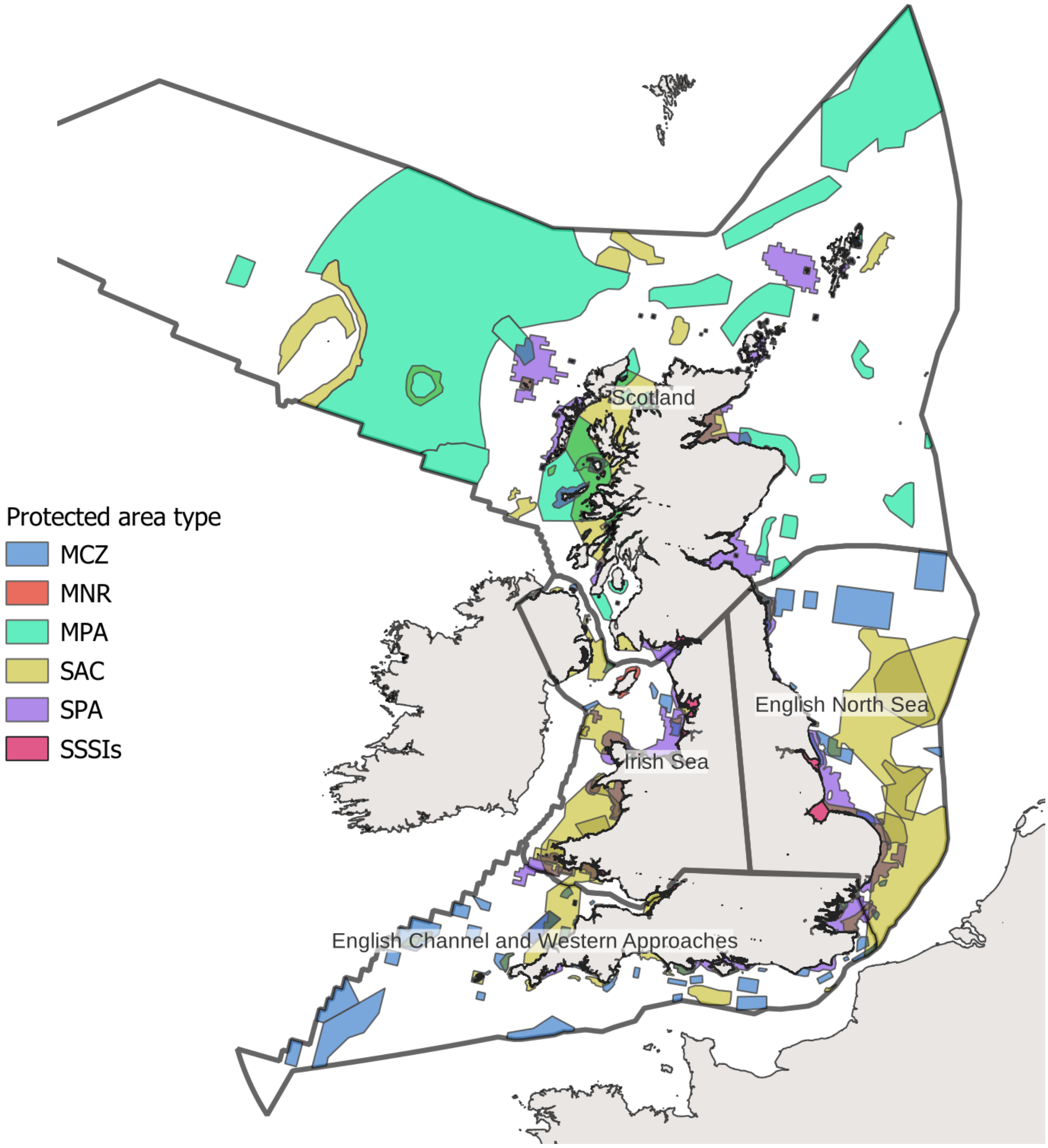

Figure 1. The UK's marine protected areas, showing the four UK Blue Carbon Inventory Regions. Protected area types include Marine Conservation Zones (MCZs) in England and Wales, Marine Protected Areas (MPAs) in Scotland, Marine Nature Reserves (MNRs) in the Isle of Man, and Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) in all devolved administrations. SSSIs and ASSIs are included in this study, but are predominantly small and coastal.

1.3 GIS methods

Common methods, outlined below, were used in each of the regional reports that make up this series, adopting and developing those used for the report on blue carbon in the English North Sea Region (Burrows *et al*., 2021).

1.3.1 Data sources for habitats and marine protected areas (MPAs)

For a first evaluation of the blue carbon habitats of the UK (see Section 2), biotope map data were downloaded, inspected and assessed. Sources of habitat information used are listed in Annex 1, but for the regional reports and this UK-scale summary the primary sources of seabed data used for deriving estimates for habitat extents were the EUSeaMap 2019 and Natural England Marine Habitats and Species Open Data (see Section 2). These datasets covered most of the UK seabed across the regional seas, but excluded areas close inshore in Scotland, for example, with a consequent under-representation of such areas. The high-resolution polygon data allowed the intersection of habitats with protected area boundaries to determine the extent of habitats within each protected area. This analysis permits scaling up of habitat-specific carbon in long-term stores and sequestration rates to whole protected areas and all of the UK's seas. Habitat extents (in km^2) were estimated for all protected areas using GIS and the statistical package "R".

1.3.2 MPA carbon in long-term stores

Carbon in long-term stores for the four regions and individual protected areas were estimated from existing spatial 500-m scale gridded data for densities (g/m^2) of OC and inorganic carbon (IC) in surface sediments (depth of less than 0.1 m). Carbon density maps (OC: see Figure 2) covered most of the UK's Exclusive Economic Zone (EEZ) except for the areas around Rockall and the extreme north. Carbon density values for each protected area (MPAs, MCZs, MNRs, SACs, SPAs and SSSIs) were extracted from these gridded datasets by selecting grid cells that lay inside the protected area boundaries. Total carbon (OC and IC) for each region and protected area was calculated as the product of the area of mapped carbon densities and the average carbon density per unit area (g $C/m^2/yr$).

1.3.3 MPA carbon accumulation from habitat-specific assimilation rates

As in previous assessments (Burrows *et al*., 2014, 2017), area-specific process rates for carbon fixation by algae and plants, the rates of import and export of particulate organic carbon (POC), production of IC as shell material and other rates were derived from literature reviews for each component habitat. Total accumulations of OC per year were derived from the products of component habitat areas and habitat-specific process rates.

2 Blue Carbon Habitats of the UK

This section reviews the carbon production, storage and sequestration potential for each blue carbon habitat, based on the existing literature and data. The glossary (see Section 7) provides definitions of the technical terms used here.

2.1 Seabed sediments

Marine sediments are the largest feature on the planet, extending over 360 million km^2 (Eakins and Sharman, 2007) and covering 70% of the Earth's surface. The composition of marine sediments is highly variable and consists of volcanic debris, living organisms (e.g., phytoplankton), unconsolidated rock particles, authigenic precipitates (crystallised minerals, e.g., carbonates), cosmogenic deposits, water and OC (LaRowe *et al*., 2020a). Globally, marine sediments form one of the largest stores of OC. Within marine sediments, microbes work to degrade the OC throughout the sediment column. In doing so, microbial processing of OC in sediments plays a role in governing atmospheric CO_2, O_2 and methane (CH_4) levels (Arndt *et al*., 2013; Berner, 2006; Burdige, 2007; Wadham *et al*., 2013).

2.1.1 Carbon in long-term stores

The quantity and distribution of carbon in long-term stores in UK seas presented in this series of reports are derived from the analysis of surface sediment samples by the British Geological Survey over the last few decades. The information from these samples has been integrated into a gridded map of estimated OC and IC densities (kg/m^2) at a 500-m resolution scale (Smeaton *et al*., 2021a) (see Figure 2). These maps have allowed a detailed breakdown of sediment carbon stores by region and by marine protected areas of all types across the UK's EEZ. The method used to calculate total carbon in long-term stores in this series of reports was the same as that described by Smeaton *et al*. (2021a), based on spatially modelled area-specific OC density values (kg/m^2). Although the total sediment organic carbon estimated here across the UK's EEZ (240 Mt OC, 1,189 Mt IC; see Table 1) is less than that reported by Smeaton *et al*. (2021a) (524 Mt OC, 2,582 Mt IC), the OC total for the UK in their study has been recently reviewed and is now thought to be in line with the estimate given here (Craig Smeaton, personal communication). Patterns of relative quantities of carbon content are central to the purposes of this report in identifying the key areas of important stores and their relationship to the set of UK marine protected areas.

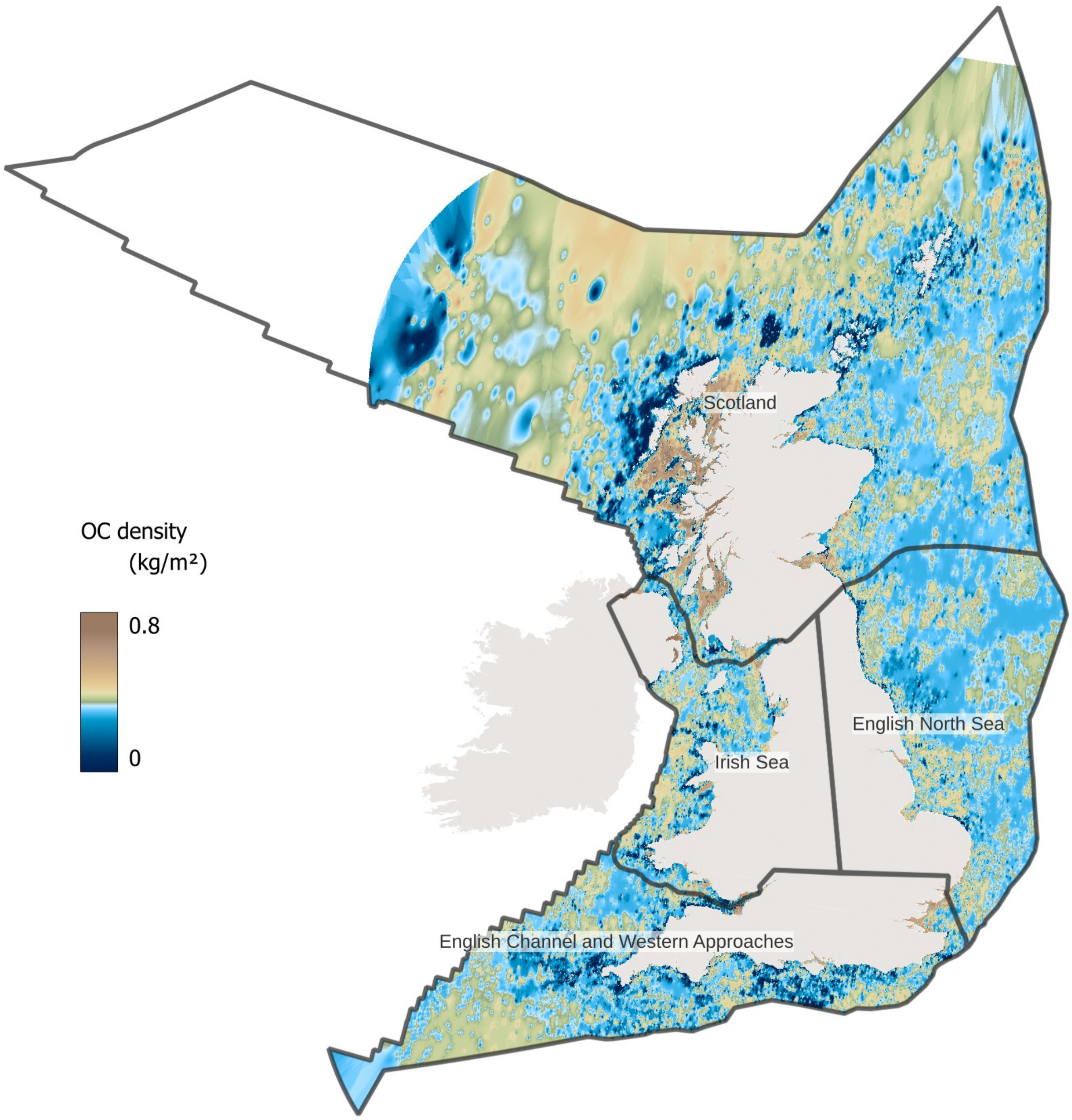

Figure 2. Organic carbon (OC) density in seabed sediments across the UK's Exclusive Economic Zone (EEZ). (From Smeaton et al.*, 2021a.)*

Table 1. Carbon density and mapped carbon in long-term stores in the top 10 cm of seabed sediments across UK Regions based on sediment organic carbon (OC) and inorganic carbon (IC) density estimates from Smeaton et al. *(2021a). Merged marine protected areas (MPAs) refer to the areas covered by overlapping MPA designations (see Figure 13)*

Estimate\Region name	**English Channel and Western Approaches**	**Irish Sea**	**English North Sea**[a]	**Scotland**	**UK**
Inside merged MPAs					
OC density (kg/m²)	0.3151	0.3321	0.3365	0.3646	0.3371
IC density (kg/m²)	0.8965	0.2563	0.5190	2.5026	1.0436
OC stored (Mt)	9.5	7.0	19.7	69.0	105.2
IC stored (Mt)	26.8	5.4	30.3	471.8	534.2
Area (km²)	30,621	21,483	58,690	211,471	322,265
Whole Region (inside and outside MPAs)					
OC density (kg/m²)	0.3215	0.3414	0.3292	0.3468	0.3347
IC density (kg/m²)	0.8117	0.3565	0.5536	2.3311	1.0132
OC stored (Mt)	35.8	14.7	37.5	151.8	239.9[d]
IC stored (Mt)	90.5	15.4	63.0	1,020.7	1,189.6
Area (km²)[b]	115,378	42,629	113,599	437,883[c]	888,991
% OC in merged MPAs	27%	48%	53%	45%	44%
% IC in merged MPAs	30%	35%	48%	46%	45%
% area in merged MPAs	27%	50%	52%	34%	36%

[a] Values for carbon stored in the North Sea region have been updated since Burrows *et al*. (2021) by inclusion of more types of marine protected area, notably SSSIs. [b] Areas here refer to the extent of the areas within the regions where organic carbon have been mapped by Smeaton *et al*. (2021a). [c] Mapped OC in long-term stores in Scotland does not cover the whole 617,385km^2 of the Region (see Figure 2), due to the study by Smeaton *et al*. (2021a) being restricted to the UK's EEZ area, which excludes the UK's continental shelf area. [d] Not including 4.2 Mt C in coastal vegetated habitats (see Table 3).

2.1.2 Sediment thickness and sediment carbon in long-term stores

The OC content of the sediments presented here originates from surface grabs around the UK. These grabs were sampled with box corers or grab samplers and are representative of the OC and IC in the top 10 cm of sediments only. The top 10 cm of marine sediments are often described as the bioturbated Holocene layer (LaRowe *et al*., 2020a).

On average, sediment thickness is believed to be greater near continental margins; an estimated global continental margin mean depth of 3,044 m has been reported by Straume *et al*. (2019). Broad datasets which estimate sediment thickness of the NE Atlantic shelf are available (see Figure 3) (see also Straume *et al*., 2019). These broad categorisations of sediment thickness estimate where marine sediments meet the basement crust (or the top of the igneous rock layer), and suggest that sediments over 500 m thick are not uncommon around the UK's EEZ. The mean depth (±standard deviation) of sediments within the UK's EEZ taken from the same dataset was 3,200 ± 2,400 m (median 2,590 m). Therefore a calculation of sediment volume (multiplying by 729,930 km^2) gives an approximate estimate of 2.3×10^6 km^3. However, these data are extrapolated from seismic refraction surveys (based on the differences in refraction of seismic waves by different categories of rock, soils or sediments), which might miss sections of sediments that are particularly close to the UK coastal region (see Funck *et al*., 2017). Furthermore, there are likely to be various layers of different sediment types within the data presented, each containing different densities of OC and IC. The OC and IC found within these thick sediment deposits have developed over millions of years and are not linked to modern blue carbon habitats. Within the UK's EEZ the thickness of the Quaternary sediment (deposited within the last 2.6 million years) is in the range of 0–30 m in most coastal regions, extending to over 50 m offshore (British Geological Survey, 2014), with only a small fraction derived from the Holocene (the time since the end of the most recent glacial period). Postglacial Holocene sediments vary in depth from less than 5 cm in the Faroe-Shetland Channel (Stoker *et al*., 1991) to tens of metres in inshore coastal environments such as fjords (Smeaton *et al*., 2017), and across the continental shelf on average Holocene sediments are *c*. 1 m thick (Furze *et al*., 2014; Scourse *et al*., 2019; Woods *et al*., 2019). As with older sediment, much of the OC held within the Holocene postglacial sediment has little relevance to modern climate, yet its shallow nature potentially places it at risk from both anthropogenic and natural disturbance, and therefore it needs to be taken into consideration. However, the lack of OC data from these depths hinders the quantification of Holocene OC, and extrapolation of the 10-cm OC store to a depth of 1 m would probably result in a significant overestimation of the OC held within these sediments. In addition, areas such as the English North Sea and Cardigan Bay have only been marine environments for a relatively short period of time, with Doggerland being flooded around 7,000–8,000 BCE (Gaffney *et al*., 2007), which means that the sediments and OC in these areas preceding this period are largely terrestrial.

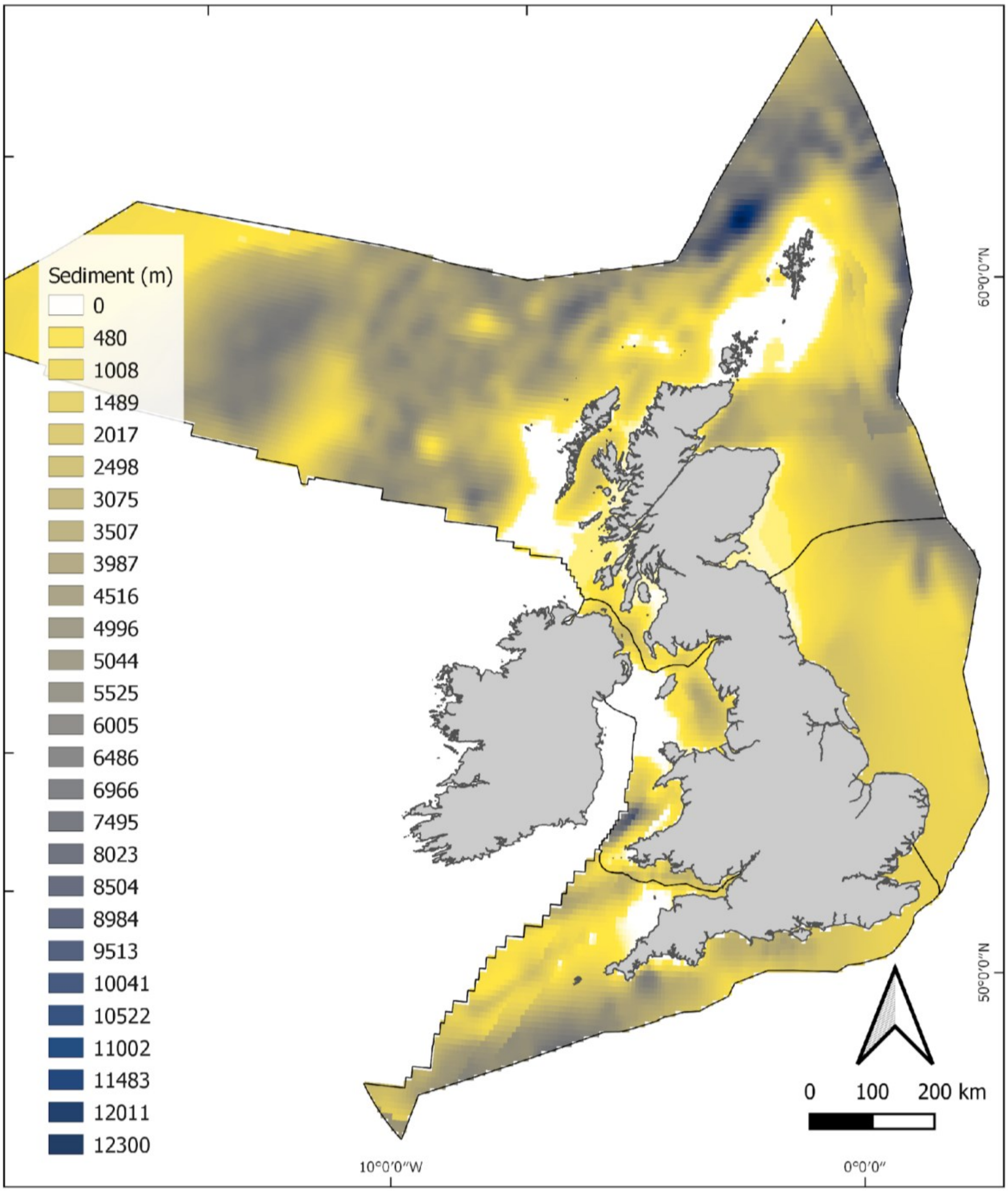

Figure 3. Total sediment thickness in the UK's EEZ and Isle of Man Territorial Seas. Sediments are thickest in the northern Scottish region to the west of Orkney. Data are downloaded from Straume et al. *(2019) and clipped to the UK's EEZ, continental shelf and Isle of Man Territorial Seas.*

Table 2. Extent (km²) of seabed habitats in the four UK Regions studied (including the Isle of Man waters) and their MPAs. Estimates for the Scotland Region are based on EUSeaMap 2019 data, whereas those for the Irish Sea, English Channel and Western Approaches and English North Sea Regions are based on Natural England Marine Habitats and Species Open Data. EUSeaMap 2019 data lack coverage of intertidal and nearshore habitats in Scotland, so are not comprehensive for that Region. Areas are summed for types of designation of MPA for each Region.

Region	EUNIS name		All	MCZ	MPA	MNR	SAC	SPA	SSSI
				Scotland					
Littoral habitats: physical	Littoral rock and other hard substrata	A1	0		0	0	0	0	0
	Infralittoral rock and other hard substrata	A3	1,336		144	0	227	43	1
	Littoral coarse sediment	A2.1	0		0	0	0	0	0
	Littoral sand and muddy sand	A2.2	0		0	0	0	0	0
	Littoral mud	A2.3	0		0	0	0	0	0
	Littoral mixed sediments	A2.4	0		0	0	0	0	0
Littoral habitats: biogenic	Coastal saltmarshes and saline reedbeds	A2.5	0		0	0	0	0	0
	Littoral sediments dominated by aquatic angiosperms	A2.6	0		0	0	0	0	0
	Littoral biogenic reefs	A2.7	0		0	0	0	0	0
	Features of littoral sediment	A2.8	0		0	0	0	0	0
Sublittoral habitats	Sublittoral rock and other hard substrata	A4	14		2	0	3	0	0
	Sublittoral sediment	A5	5,480		77	1	170	233	2
	Sublittoral coarse sediment	A5.1	68,276		10,919	6,983	4,140	3,881	3
	Sublittoral sand	A5.2	110,712		8,522	5,240	2,879	3,367	79
	Sublittoral mud	A5.3	59,575		8,214	1,608	6,703	1,134	18
	Sublittoral mixed sediments	A5.4	3,431		841	93	1,337	316	3
	Angiosperm communities in reduced salinity	A5.5	0		0	0	0	0	0
	Sublittoral biogenic reefs	A5.6	0		0	0	0	0	0
	Deep seabed	A6	35,331		6,882	831	2,749	292	0
	Deep-sea mixed	A6.2	47,096		18,256	7,560	1,609	0	0
	Deep-sea sand	A6.3	52,570		9,743	968	3,300	442	0
	Deep-sea mud	A6.5	223,922		109,847	27,136	4,366	8	0
	Habitat not assigned	NA*	5,646		1,474	0	2,981	15	70
				Irish Sea					
	Littoral rock and other hard substrata	A1.2	73	5		0	44	1	31
Littoral habitats: physical	Infralittoral rock and other hard substrata	A3.1	104	7		0	104	5	2
	Littoral coarse sediment	A2.1	16	1		0	9	0	5
	Littoral sand and muddy sand	A2.2	891	96		0	638	81	612

Region	EUNIS name		All	MCZ	MPA	MNR	SAC	SPA	SSSI
	Littoral mud	A2.3	233	30		0	166	1	196
	Littoral mixed sediments	A2.4	15	7		0	12	0	11
	Coastal saltmarshes and saline reedbeds	A2.5	146	6		0	75	0	48
Littoral habitats: biogenic	Littoral sediments dominated by aquatic angiosperms	A2.6	5	0		0	5	0	5
	Littoral biogenic reefs	A2.7	34	7		0	19	0	14
	Features of littoral sediment	A2.8	2	0		0	1	0	1
Sublittoral habitats	Sublittoral rock and other hard substrata	A4	1,152	0		0	1	0	0
	Sublittoral sediment	A5	513	12		13	217	3	0
	Sublittoral coarse sediment	A5.1	19,860	105		293	7,770	576	10
	Sublittoral sand	A5.2	9,379	270		39	4,235	2,134	90
	Sublittoral mud	A5.3	6,594	277		1	1,113	154	30
	Sublittoral mixed sediments	A5.4	2,361	15		2	847	26	0
	Angiosperm communities in reduced salinity	A5.5	0	0		0	9	0	1
	Sublittoral biogenic reefs	A5.6	,0	2		0	15	0	1
	Deep seabed	A6	0	0		0	0	0	0
	Deep-sea sand	A6.3	0	0		0	0	0	0
	Deep-sea mud	A6.5	0	0		0	0	0	0
	English Channel and Western Approaches								
Littoral habitats: physical	Littoral rock and other hard substrata	A1	58.9	59	21			0	0
	Infralittoral rock and other hard substrata	A3	514	100			0	0	0
	Littoral coarse sediment	A2.1	19	3			0	0	0
	Littoral sand and muddy sand	A2.2	135	26			1	1	1
	Littoral mud	A2.3	390	171			0	1	1
	Littoral mixed sediments	A2.4	21	2			0	1	1
	Coastal saltmarshes and saline reedbeds	A2.5	121	15			1	0	0
	Littoral sediments dominated by aquatic angiosperms	A2.6	10	0			0	1	1
	Littoral biogenic reefs	A2.7	3	0			1	1	1
	Features of littoral sediment	A2.8	1	0			0	1	1
Sublittoral habitats	Sublittoral rock and other hard substrata	A4	3,505	993			0	0	0
	Sublittoral sediment	A5	619	82			0	0	0
	Sublittoral coarse sediment	A5.1	15,194	3,541			0	0	0
	Sublittoral sand	A5.2	69,720	11,674			0	0	0
	Sublittoral mud	A5.3	9,300	1,212			0	0	0
	Sublittoral mixed sediments	A5.4	4,281	769			0	0	0
	Angiosperm communities in reduced salinity	A5.5	27	4			1	1	0

Region	EUNIS name		All	MCZ	MPA	MNR	SAC	SPA	SSSI
	Sublittoral biogenic reefs	A5.6	130	47			1	0	0
	Deep seabed	A6	1,376	330			0	0	0
	Deep-sea sand	A6.3	82	68			0	0	0
	Deep-sea mud	A6.5	363	70			0	0	0
			English North Sea						
	Littoral rock and other hard substrata	A1.2	13	9	0	0	5	13	11
Littoral habitats: physical	Infralittoral rock and other hard substrata	A3.1	141	105	0	0	82	91	4
	Littoral coarse sediment	A2.1	6	1	0	0	2	4	3
	Littoral sand and muddy sand	A2.2	248	15	0	0	198	257	198
	Littoral mud	A2.3	147	0	0	0	128	113	109
	Littoral mixed sediments	A2.4	11	3	0	0	6	10	3
Littoral habitats: biogenic	Coastal saltmarshes and saline reedbeds	A2.5	127	0	0	0	112	55	46
	Littoral sediments dominated by aquatic angiosperms	A2.6	6	0	0	0	6	12	6
	Littoral biogenic reefs	A2.7	3	0	0	0	3	4	3
	Features of littoral sediment	A2.8	1	0	0	0	0	1	1
Sublittoral habitats	Infralittoral rock and other hard substrata	A3	141	105	0	0	82	91	4
	Sublittoral rock and other hard substrata	A4	655	276	0	0	179	197	2
	Sublittoral sediment	A5	45	7	0	0	14	34	3
	Sublittoral coarse sediment	A5.1	19,514	2,385	0	0	11,711	2,141	31
	Sublittoral sand	A5.2	81,421	7,644	1	1	40,987	2,416	361
	Sublittoral mud	A5.3	5,444	249	0	0	431	308	115
	Sublittoral mixed sediments	A5.4	5,105	903	0	0	1,669	1,723	54
Sublittoral habitats: biogenic	Sublittoral biogenic reefs	A5.6	272	0	0	0	324	126	3

* NA indicates not applicable.

2.1.3 Seabed habitats and sediment types and their rates of accumulation of organic carbon

All the estimates of the rates of sequestration of OC across regions and types of MPA in this series of reports were based on mapped information on the distribution of seabed types (see Table 2).

After extensive reviews of the literature (see regional reports), the most up-to-date and relevant published rates of sediment accumulation and OC content for seabed types were combined across the areas of interest (region or MPA) using the estimated area of each type of habitat present to give rates of carbon accumulation across whole areas as t C/yr (also expressed as kt C/yr or Mt C/yr). Area-average rates of accumulation were obtained by dividing the summed yearly accumulation by the total area of habitats within each region or MPA boundary, and expressed as g C/m^2/yr.

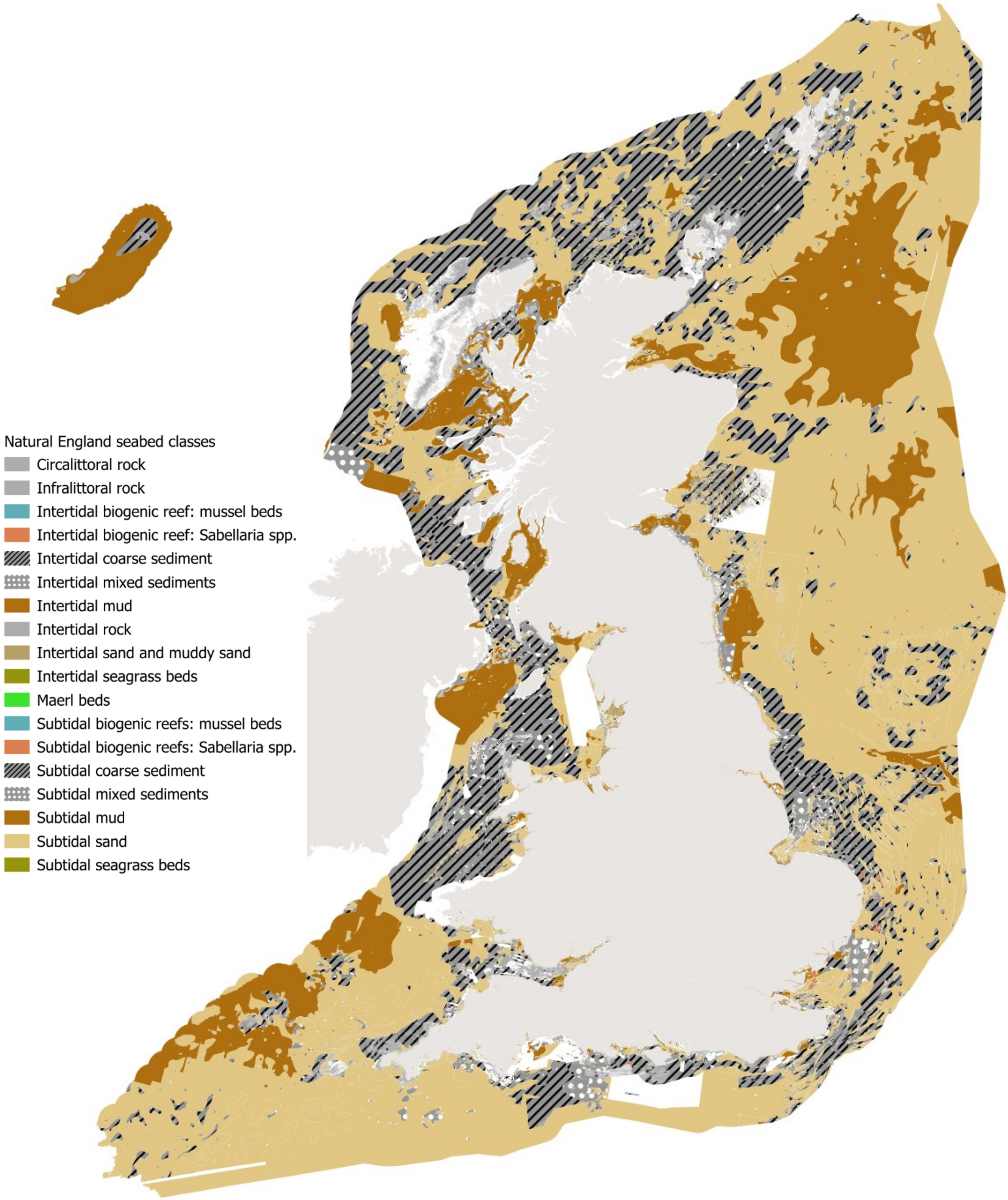

Figure 4. Seabed sediment types from Natural England Marine Habitats and Species Open Data. Classes show the major types from muds and sands, through mixed and coarse sediments to rock habitats. Rates of OC accumulation approximately follow the sequence of high rates in mud habitats, lower rates in sand and coarse sediments, and zero accumulation in rock habitats. Biogenic reefs including mussels and Sabellaria *reefs, seagrasses and maerl beds are too small to be visible at this scale. Note that data are missing for some geographical areas (see Figure 5 for more complete coverage of the seabed).*

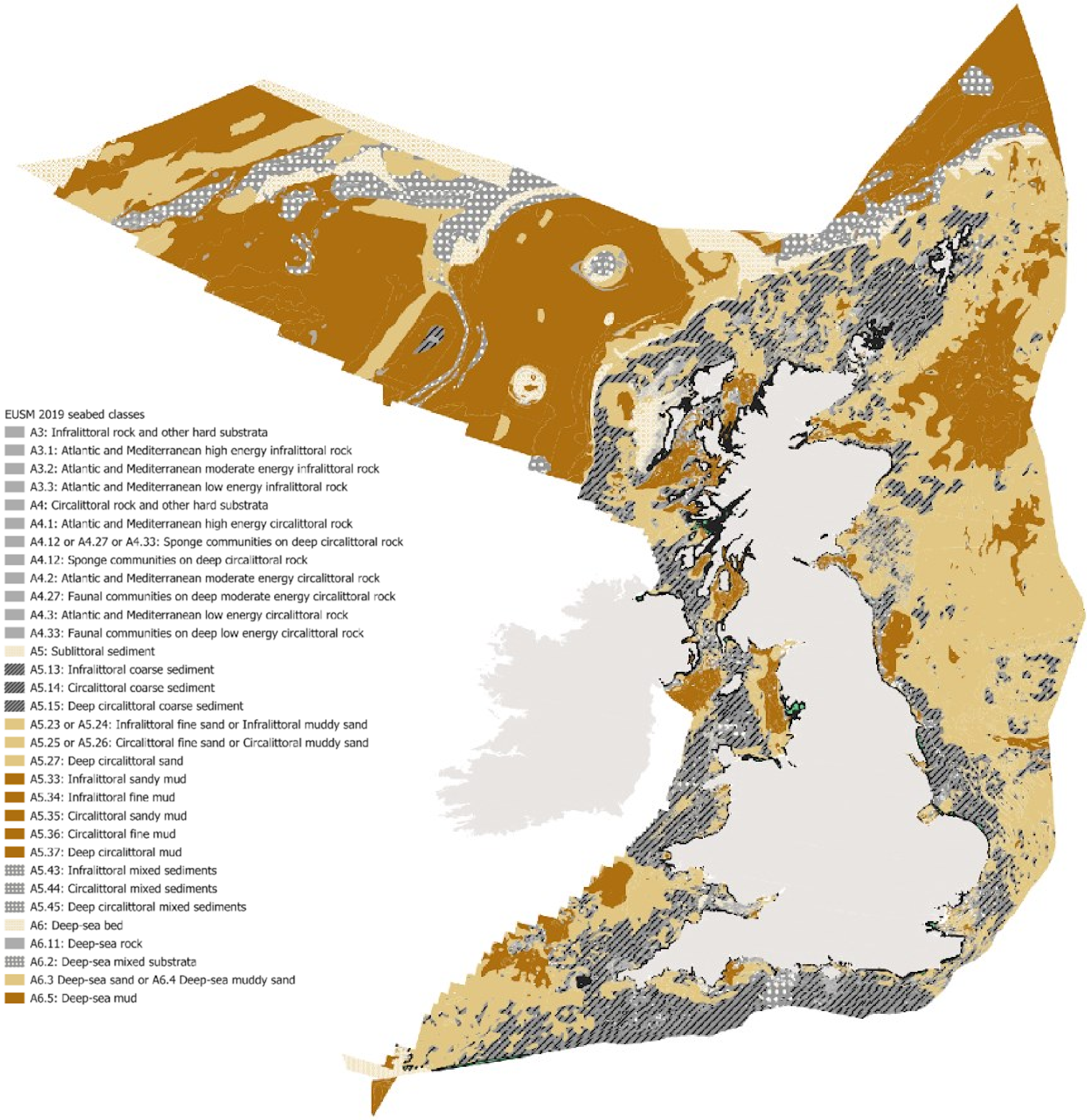

Figure 5. Seabed sediment types from EMODnet Seabed Habitats data (EUSeaMap 2019). Classes show the major seabed types with their EUNIS Level 3 codes, with shading and colours aligned with Figure 4. EUSeaMap 2019 lacks detailed information on inshore biogenic and coastal vegetated habitats, but gives more complete coverage offshore than Natural England Habitats and Species Open Data.

2.2 Coastal vegetated habitats: blue carbon habitats *sensu stricto*

2.2.1 Estimating habitat extents

Certainty about the extents of coastal vegetated blue carbon habitats varies. Because of their accessibility and their amenability to remote sensing, saltmarsh extents are well known, extensively documented (Austin *et al*., 2021; Environment Agency, 2022; Haynes, 2016; Smeaton *et al*., 2021b) and GIS data on their occurrence are available from several sources, including the UK Centre for Ecology & Hydrology (UKCEH) Land Use data, the Environment Agency and Natural England Habitats and Species Open Data. In contrast, relatively little is known about intertidal macroalgae, seagrass beds and kelp beds, with estimates of their known extents limited to a very small number of explicitly mapped locations, such as the NatureScot GeMS Scottish Priority Marine Features (PMF) database, but supplemented by much larger datasets on the occurrence of these habitats at point locations, namely the National Biodiversity Network (NBN) Gateway, Ocean Biodiversity Information System (OBIS), Global Biodiversity Information Facility (GBIF) and GeMS Species Point Dataset. In the absence of mapped habitat data, extents for seagrass beds and kelp habitats have been estimated using the output of habitat suitability models. For seagrass, the Joint Nature Conservation Committee (JNCC) has habitat suitability models that predict *Zostera marina* habitats (Castle *et al*., 2022), with extensive areas predicted to be suitable for seagrass around the sandy coastal areas of England and Wales, much greater than the known extent of such habitats. The mismatch between predictions and observations has reinforced the perception of widespread loss of this particular habitat (Green *et al*., 2021). The reduction in seagrass area compared with its historical extent is real, but only partially revealed by the models. Similar modelling efforts in the UK (Burrows *et al*., 2014, 2018) and in Norway (Bekkby *et al*., 2009) also give estimates of the likely extent of kelp habitats; the extents thus derived underpin the extent values used in this series of reports. Modelled data are highly uncertain, especially without good prediction layers, even when the uncertainty in the statistical parameters is evaluated. Habitat extent estimates from models usually require a threshold level of predicted abundance or likelihood of presence to be set before summing areas across a model grid. When these thresholds are set low, the extent predicted can be quite large. Yesson *et al*. (2015) predicted that an area of 19,000km^2 (nearly the area of Wales) is suitable for kelp around the UK, based on the threshold of presence of species in 3 × 3 km areas. For this report, thresholds of kelp biomass were used that were typical of places where experimental studies have measured production rates (Smale *et al*., 2020), yet these thresholds may have produced overestimates. For the Scotland Region report, a threshold of predicted kelp biomass of 0.5 kg/m^2 produced an estimate of kelp habitat extent of 4,778 km^2 for the Region (see Figure 6). A more typical biomass of 10 kg/m^2 for a dense kelp bed gave a smaller estimate of 993 km^2. Whichever is the most appropriate, the plot in Figure 6 shows the extreme sensitivity of extent estimates to chosen thresholds.

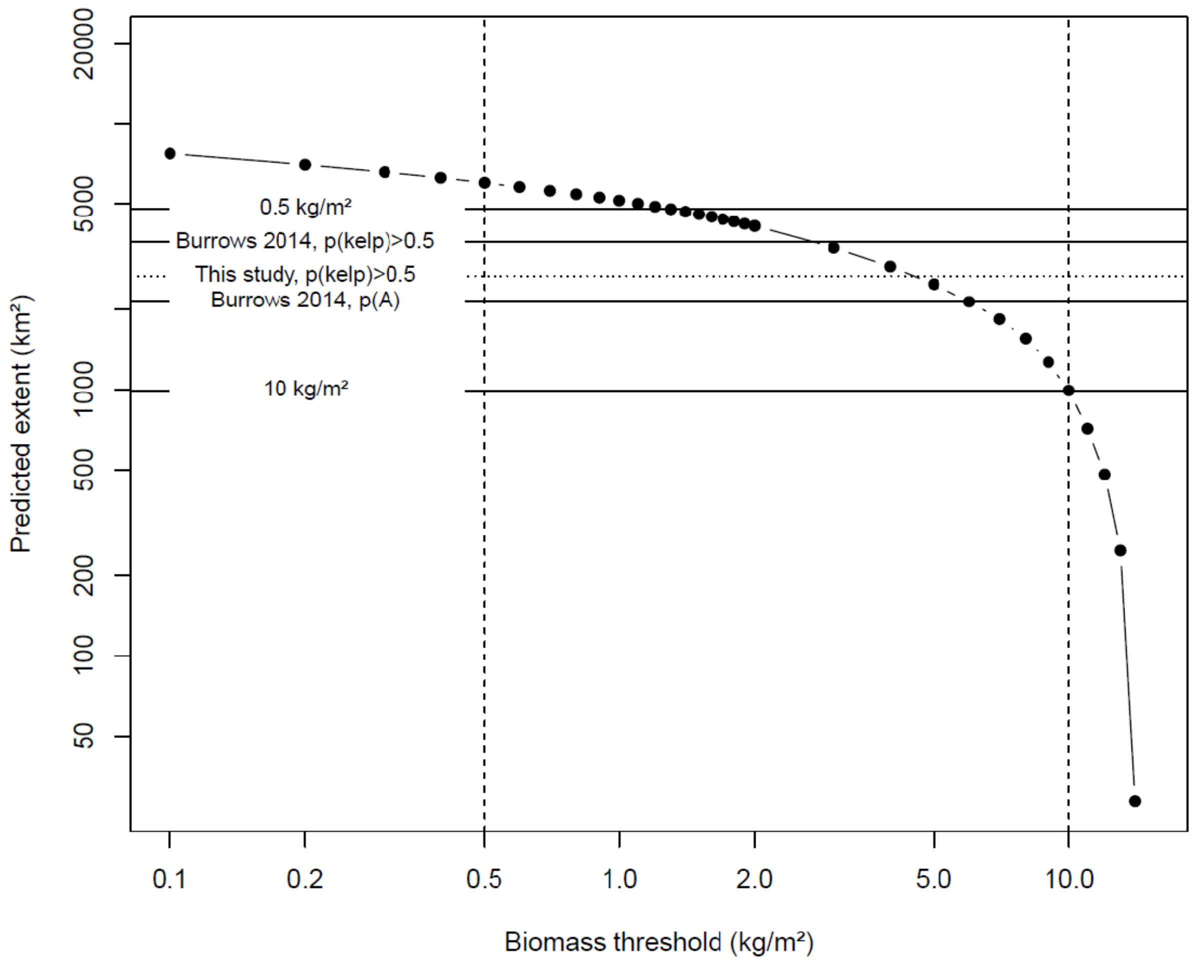

Figure 6. Effects of changing thresholds on extent estimation for kelp (Laminaria hyperborea) *habitat in Scotland. The plot shows the dependence of the predicted extent of kelp habitat on the threshold of predicted abundance. Broken vertical lines show 0.5 kg/m^2 and 10 kg/m^2, the latter value being typical for dense kelp beds. Solid horizontal lines show kelp habitat extents estimated for the same region in previous studies (Burrows* et al.*, 2014), with the extent estimate for kelp habitats taken from the area where presence of kelp was more likely than not (p(kelp) > 0.5).*

For seagrass beds, modelled values were used not to express habitat extents, but rather the known extents of existing beds. Seagrass has been the focus of a greater research and survey effort in recent years, including citizen science (https://seagrassspotter.org/explore/map) and academic studies (Jones and Unsworth, 2016). In contrast with the use of models to estimate kelp habitats, using known records alone is likely to have resulted in an underestimate of the true extent of subtidal (*Zostera marina*) and intertidal (*Zostera noltii*) beds across the UK Regions.

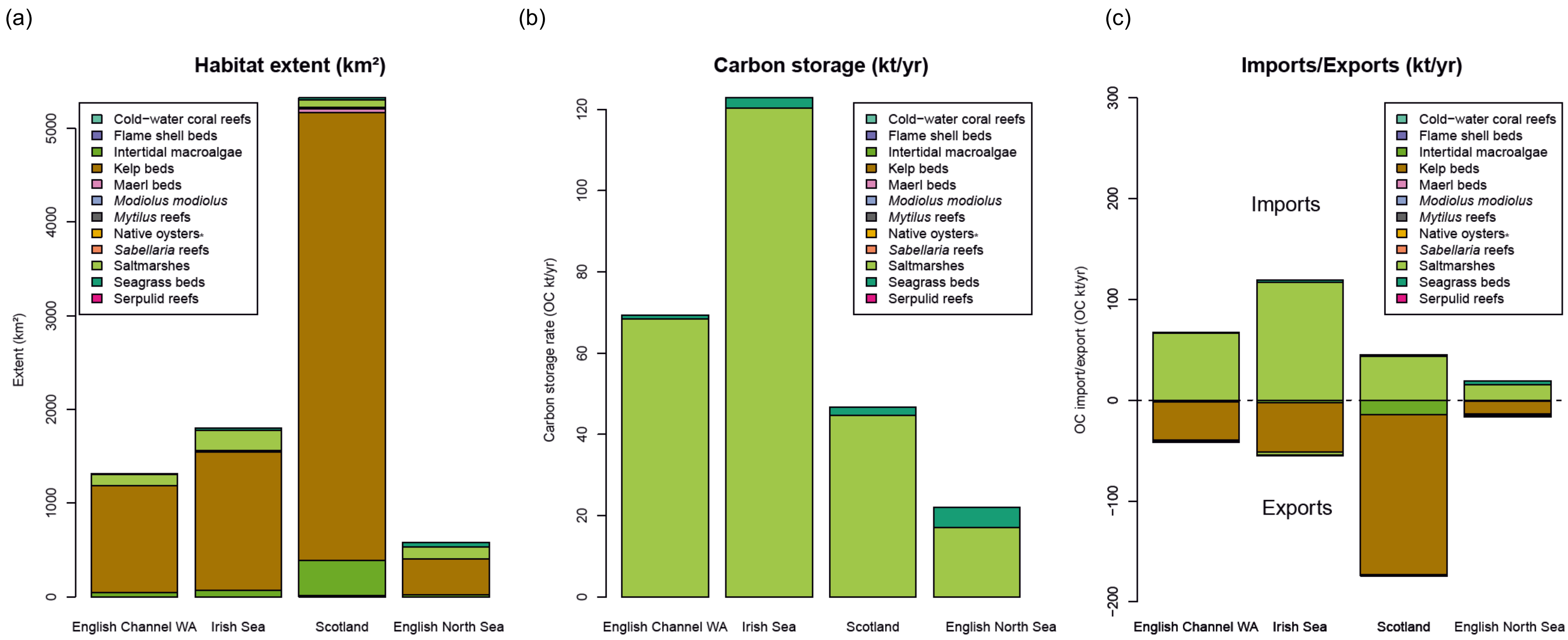

Figure 7. Coastal vegetated blue carbon and biogenic habitats summarised across UK Regions. (a) Habitat extent. (b) Rates of organic carbon storage (kt OC/yr). (c) Imports (positive values) and exports (negative values) of organic carbon summed across all habitats within each Region.

A different approach was taken to assess the likely extent of intertidal macroalgae. Low and high tide lines are available as mapped layers from Ordnance Survey Open Data in shapefile format. Here an assumption of 30% cover of intertidal rock by macroalgae was combined to give estimates of carbon in long-term stores in living material and to scale production rates to carbon totals for whole Regions.

2.2.2 Carbon in long-term stores and rates of accumulation

Carbon densities (g OC/m^2 and g IC g/m^2), accumulation rates (per unit area in g C/m^2/yr and totals in t C/yr) have been estimated for each of the coastal vegetated blue carbon habitats from reported values in published studies considered to be most relevant at the UK and regional scales (see Table 3), and can be compared with sediment carbon in long-term stores for each Region (see Table 1).

Overall these data show that kelp beds are the most extensive of the coastal vegetated habitats (see Table 4 and Figure 7a), albeit with the caveat that habitat extents for kelp are uncertain and subject to the arbitrary selection of an abundance threshold. Kelp habitats are predicted to be most extensive in Scotland, reflecting the much greater extent of shallow rocky coastlines suitable for kelps as well as most of the historical records of kelp habitats across the UK. After kelp habitats, saltmarshes are the most extensive coastal vegetated habitats in all regions except for Scotland, where intertidal macroalgae cover a greater area.

Saltmarshes are much larger stores of carbon than seagrass beds, due to their greater extent rather than to any large difference in the rates of carbon accumulation (see Table 4 and Figure 7b). The Irish Sea Region has much more extensive saltmarshes than the other three Regions, and consequently a much greater estimated storage rate. The extent of seagrass beds in the English North Sea Region was revised downwards from 49.3 km^2 in the original report for that study Region (Burrows *et al.*, 2021) to 8.9 km^2 following a more recent review (Green *et al.*, 2021). Higher values for habitat extents usually result from the use of habitat suitability models rather than direct mapping data.

A useful way to picture the dynamics of carbon exchanges among habitats is to compare the carbon exported from habitats as plant or algal detritus (outflux in Table 4 and exports in Figure 7c) with the amount stored across all the habitats in each Region (influx in Table 4 and imports in Figure 7c). Coastal vegetated blue carbon habitats in the Irish Sea are dominated by the import of OC to saltmarshes, with import to saltmarshes considerably greater than export of detritus from kelp beds and seagrasses. This contrasts with the balance in Scotland, where coastal vegetated blue carbon habitats are net exporters of OC due to the extensive and highly productive kelp beds in the Region.

Table 3. Organic carbon in long-term stores and sequestration capacity in the UK. The values shown summarise carbon store and extent estimates presented in the habitat reviews (see Sections 2.1 to 2.6), and the description of sediment carbon stores (see Section 2.7). Grey tinted cells indicate that no data were available or there was insufficient evidence to present values with confidence.

Region	Habitat	Extent (km^2)	Store total (Mt C) at 0.1 m depth	Store density (g C/m^2)	Production rate (g $C/m^2/yr$)	Total production (1,000 t C/yr)	Outflux (1,000 t C/yr)	Influx (1,000 t C/yr)	Storage rate (g $C/m^2/yr$)	Storage capacity (1,000 t C/yr)
Scotland	Phytoplankton	617,385			81	50,233	5,023			
	All sediment [a]	437,883	151.8	346.8				9,471	15.7	9,471
	CVBC*/ biogenic habitats	5,228	1.5	289.6	328	1,736	174	8	1.5	8
Irish Sea	Phytoplankton	43,112			81	3,508	351			
	All sediment	43,112	14.7	341.4				1,145	30.2	1,145
	CVBC/biogenic habitats	1,800	1.2	670.5	307	549	55	119	66.2	119
English Channel and Western Approaches	Phytoplankton	111,469			81	9,069	907			
	All sediment	111,469	35.8	321.5				1,730	17.4	1,730
	CVBC/biogenic habitats	1,318	0.7	503.0	315	416	42	67	51.2	67
English North Sea	Phytoplankton	113,947			81	9,271	927			
	All sediment	113,947	37.5	329.1				1,190	10.4	1,190
	Biogenic habitats	584	0.8	1,299.1	285	165	17	77	131.0	77
All UK	Phytoplankton	885,913	0.0			72,081	7,208	0		0
	All sediment	706,411	239.9			0	0	13,535		13,535
	CVBC/biogenic habitats	8,931	4.1			2,866	287	271		271

a Extents of sediment habitats are derived from mapped areas in Smeaton *et al*. (2021a), and are mostly not overlapping with those of shallow inshore CVBC habitats. * CVBC, coastal vegetated blue carbon.

Table 4. Extents, quantity in long-term stores and rates of accumulation of organic carbon in the UK's coastal vegetated blue carbon and biogenic habitats, summarised from values provided in this series of reports. Grey tinted cells indicate that there were insufficient data to allow a credible estimation. Outflux refers to the quantity exported from plants, and influx refers to the quantity of carbon added to habitat-specific stores.

Region	Habitat	Extent (km²)	Store (1,000 t C)	Store (g C/m²)	Production rate (g C/m²/yr)	Total production (1,000 t C/yr)	Outflux (1,000 t C/yr)	Influx (1,000 t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1,000 t C/yr)
Scotland	Kelp beds	4,777.6	1,042	218	332.2	1,587.1	158.7	0	0	0
	Intertidal macroalgae	371.3	50	122	377.9	123.4	14.0	0	0	0
	Seagrass beds	20.9	32	1,547				2.1	100.4	2.1
	Saltmarshes	58.4	368	1,490	138.1	8.1	0.8	5.8	113.5	6.6
	Maerl beds	31.4	22	760						
	Serpulid reefs	1.1								
	Horse mussel (*Modiolus modiolus*) beds	10.2								
	Maerl beds and horse mussel beds (mosaic)	13.8								
	Blue mussel (*Mytilus edulis*) beds	4.4								
	Native oysters*	0								
	Flame shell beds	10.5								
	Cold-water coral reefs	6.2								
	Honeycomb worm (*Sabellaria alveolata*) reefs	1.1								
Irish Sea	Kelp beds	1,477.4	204	138	332.2	490.8	49.1	0	0	0
	Intertidal macroalgae	65.8	9	122	377.9	21.8	2.5	0	0	0
	Seagrass beds	26.0	62	2,390	274.3	7.1	0.7	1.9	100.4	2.6
	Saltmarshes	213.4	932	4,085	138.1	29.5	2.9	117.3	129.0	120.2
	Modiolus modiolus beds	0								
	Sabellaria reefs	17.9								
English Channel and Western Approaches	Kelp beds	1,141.3	102.6	89.9	332.2	379.1	37.9	0	0	0
	Intertidal macroalgae	45.1	6.1	122.3	377.9	15.0	1.7	0	0	0
	Seagrass beds	9.9	23.6	2,390.3	274.3	2.7	0.3	0.7	100.4	1.0
	Saltmarshes	121.5	530.5	4,085.0	138.1	16.8	1.7	66.8	129.0	68.4
	Modiolus modiolus beds									
	Sabellaria reefs									
English North Sea	Kelp beds	379.5	58.4	153.9	332.2	126.1	12.6	0	0	0
	Intertidal macroalgae	22.6	5.0	122.3	377.9	7.5	0.9	0	0	0
	Seagrass beds	8.9	21.3	2,390.3	274.3	2.4	0.2	4.7	100.4	5.0

Region	Habitat	Extent (km²)	Store (1,000 t C)	Store (g C/m²)	Production rate (g C/m²/yr)	Total production (1,000 t C/yr)	Outflux (1,000 t C/yr)	Influx (1,000 t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1,000 t C/yr)
	Saltmarshes	132.7	579.5	4,085.0	138.1	18.3	1.8	15.3	129.0	17.1
	Modiolus modiolus beds									
	Sabellaria reefs									
All UK	Kelp beds	7,775.7	1,406.7			2,583.1	258.3	0		0
	Intertidal macroalgae	504.8	69.7			184.7	19.1	0		0
	Seagrass beds	65.7	139.3			12.3	1.2	9.4		10.7
	Saltmarshes	526.0	2,410.1			72.7	7.3	205.2		212.4
		8,872.2	4,025.8			2,852.7	285.9	214.6		223.1

2.2.3 Saltmarsh

The UK has the most well-known and accurately mapped saltmarsh systems. These systems are exposed at low tide, making them the easiest blue carbon habitat to measure accurately. Previously reported estimates of saltmarsh extent in the UK are 470 km^2 (Beaumont *et al*., 2014), 441 km^2 (Burden *et al*., 2020) and 452 km^2 (excluding Northern Ireland) (Smeaton *et al*., 2022).

Total saltmarsh OC in long-term stores has recently (November 2023) been estimated by Smeaton *et al*. (2023) to be 5.20 ± 0.65 Mt for the whole of Great Britain, with values of 0.94 ± 0.26 Mt for Scotland, 3.64 ± 0.49 Mt for England and 0.63 ± 0.18 Mt for Wales (excluding 2.5 km^2 of saltmarshes in Northern Ireland, which represent 0.5% of the Great Britain total). These saltmarsh OC store values differ from those shown in Table 4, as they are derived from different and more recent data sources, using different regional boundaries.

Available mapped data for Northern Ireland probably overestimate the amount of saltmarsh along the coastline, and values reported in the literature range from just over 2 km^2 (Joint Nature Conservation Committee, 2004, 2018) to 31.1 km^2 (Strong *et al*., 2021). Mapped data for Scotland incorporate perched marsh regions (clifftop marshes, which contain very little soil) and may not fall under the description of blue carbon. The same is true for Wales, which includes a large amount of perched marsh, but also incorporates a region south of the River Severn and River Dee in England. Similarly, the River Severn on the Welsh side is included within the English saltmarsh dataset. Both of these overlaps will result in an overestimation of saltmarshes in the Regions.

Based on radiometric dating, Scotland's saltmarshes have been shown to accumulate 4,385 ± 481 tonnes of OC each year (Miller *et al*., 2023) at rates in the range of 29–198 g C/m^2/yr.

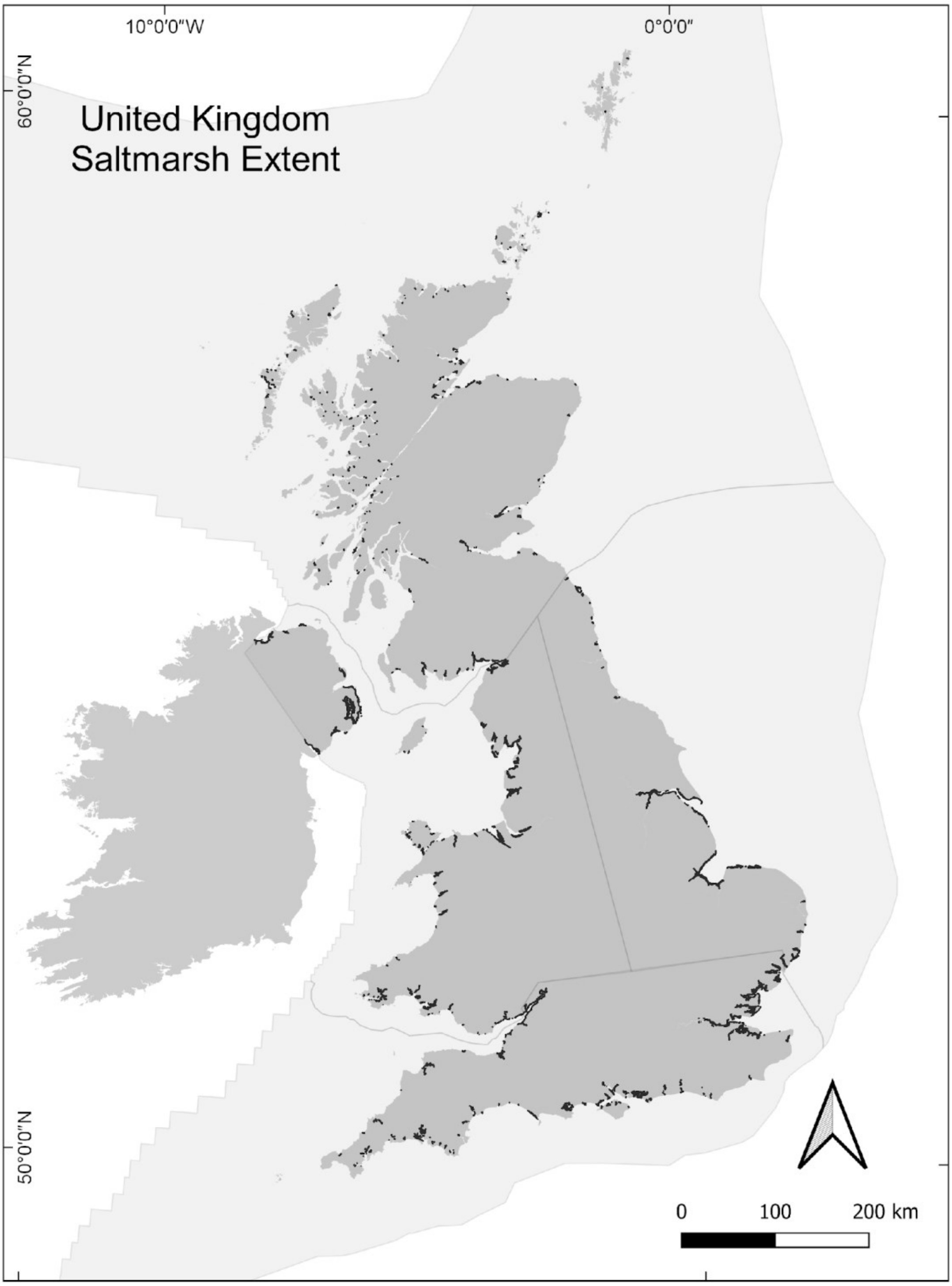

Figure 8. Combined saltmarsh spatial estimates (denoted by black areas) for the regional seas of the UK; the spatial extent on this map is not to scale. Open-source data have been used for Scotland, England and Wales (all available from Smeaton et al., *2022) and for Northern Ireland (available from DAERA at www.daera-ni.gov.uk/articles/digital-datasets). Data for the Isle of Man were provided by the Manx Blue Carbon Project for use in this report only. The combined shapefile extent gives a total of 454.1–482.8 km^2 of known saltmarsh, which is 0.06% of the surface area of the UK's EEZ, continental shelf and Isle of Man Territorial Seas.*

2.2.4 Kelp forests

Large brown algae belonging to the order Laminariales are referred to as kelps. Kelps in the UK inhabit rocky hard substrates from the infralittoral subzone to some parts of the circalittoral subzone. Kelp beds form the most extensive blue carbon habitat in the UK (see Figure 9). However, kelps are also one of the most poorly understood systems with regard to long-term sequestration of OC (Parker *et al*., 2021). Some species of kelp hold a consistent amount of biomass in the forest throughout the year (estimated at 3.3 t C/ha by O'Dell, 2022). The annual growth cycles of kelps mean that a large amount of the blade is lost as detritus between February and May each year (Krumhansl and Scheibling, 2012). This detritus is exported from the habitat to adjacent sediments or benthic communities where it is buried or consumed, or it decomposes (Krause-Jensen and Duarte, 2016). In this sense, kelp forests act as a donor habitat, contributing large amounts of OC to detritus pools.

The distribution of kelp forests throughout the UK is well documented (see Figure 9), but estimates of the extent of kelp forests are still somewhat uncertain. Much of the research in this area has been conducted in Scotland, starting with the work of Walker (1954), who conducted extensive aerial surveys and estimated that there were 10 Mt of wet kelp biomass (equivalent to 457,000 t C) over the 8,000 km^2 of Scotland's entire sublittoral zone (0–19 m depth), with 1,120 km^2 where kelp was present in harvestable quantities. More recent estimates have confirmed that kelp forests formed of *Laminaria hyperborea* and other species, including sugar kelp (*Saccharina latissima,* oarweed (*Laminaria digitata*), furbelows (*Saccorhiza polyschides*) and dabberlocks (*Alaria esculenta*), might occupy over 8,000 km^2 across the entire UK coast (Smale *et al*., 2016). Carbon accumulated and exported by kelp forests is calculated as a proportion of annual productivity (Krause-Jensen and Duarte, 2016), so an improved understanding of carbon sequestration by kelps will require a greater understanding of the extent of kelp forests. The present study estimates their extent in the UK to be 7,776 km^2 (see Table 4, discussed in Section 2.2.1), most of which is in Scotland (4778 km^2; see Figure 9), a very similar finding to that of Smale *et al.* (2016). Despite differences in the approaches used, the Scotland estimate aligns well with the 1950s estimate for Scotland (Walker, 1954). Walker's biomass threshold would have been below 3 kg/m^2 wet weight, but above the 0.5 kg/m^2 threshold used here (see Section 2.2.1), resulting in a lower but comparable estimate of kelp habitat extent (1,120 km^2 for a 3 kg/m^2 threshold, compared with 4,778 km^2 for a 0.5 kg/m^2 threshold).

Kelp habitats export 260,000 t C/yr across the UK's seas (90% of the total export from all coastal vegetated blue carbon habitats; see Table 4). Given the uncertainty about estimates of kelp habitat extent, confidence in this value is low compared with that for the size of exports from other sources.

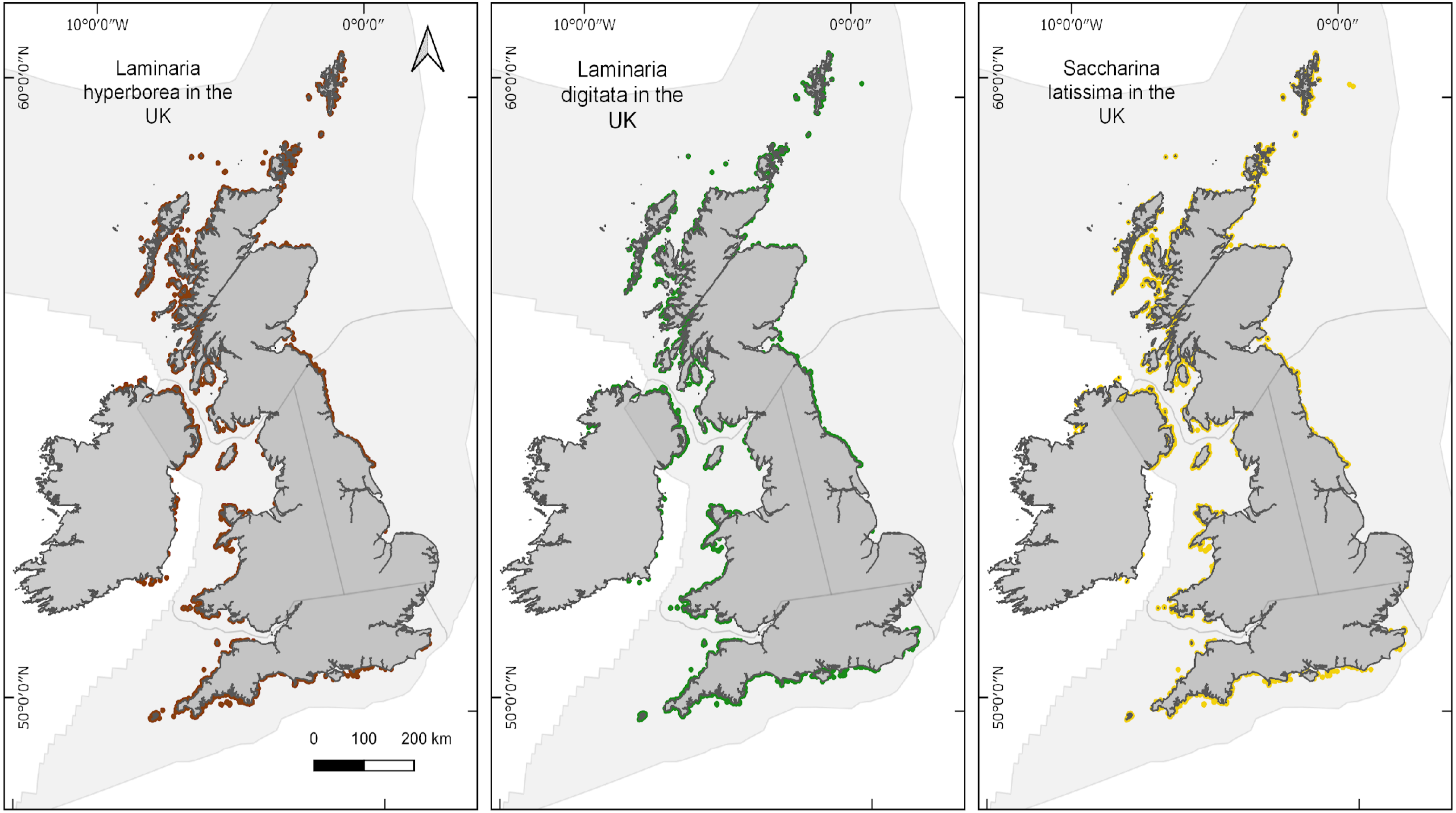

Figure 9. Distribution of point-source records for the three dominant species of stipitate kelps throughout the UK, based on the Archive for Marine Species and Habitats Data (an open –source dataset available from DASSH at www.dassh.ac.uk).

2.2.5 Intertidal seaweeds

Like kelps, intertidal seaweeds export OC to other habitats for storage. The predominantly rocky coasts of Scotland host the largest area of intertidal seaweeds (371 km^2, or 73% of the UK total; see Table 4), with most of the living biomass consisting of *Ascophyllum nodosum* in wave-sheltered areas, and the remainder being composed of *Fucus vesiculosus, Fucus spiralis* and *Fucus serratus.* Intertidal species, especially those with gas bladders, are well represented in beach-cast material (O'Dell, 2022) and have long been collected as cast or fresh material, with a significant industry focused on *Ascophyllum nodosum* harvest in the Outer Hebrides (Burrows *et al*., 2010).

Intertidal seaweed species are considered to be just as productive as kelp species, but their habitat is limited to a narrow band of rock around the UK coast (between mean high water and mean low water), and is smaller than that of kelps (Lewis, 2020). In temperate regions, productivity and detrital production of fucoid species are higher than in other areas (Hill *et al*., 2015). Within the UK no measurements of detritus output from fucoid beds were available until Lewis (2020) assessed their productivity and export in studies designed to test the blue carbon potential of these species. The present study uses an average production rate of 377.9 g $C/m^2/yr$, derived from the findings of Lewis (2020).

Intertidal macroalgae are estimated to export 19,000 t C/yr across the UK's seas (7% of the total export from all coastal vegetated blue carbon habitats; see Table 4). This export comes from an estimated 504.8 km^2 of intertidal seaweed habitat, most of which is along the Scottish coastline. Dislodgement of fucoid species that contain air vesicles can mean that detrital material is dispersed long distances away from coastal zones via surface currents, potentially reaching deeper regions where it will eventually sink into sediments (Vandendriessche *et al*., 2007; Smetacek and Zingone, 2013).

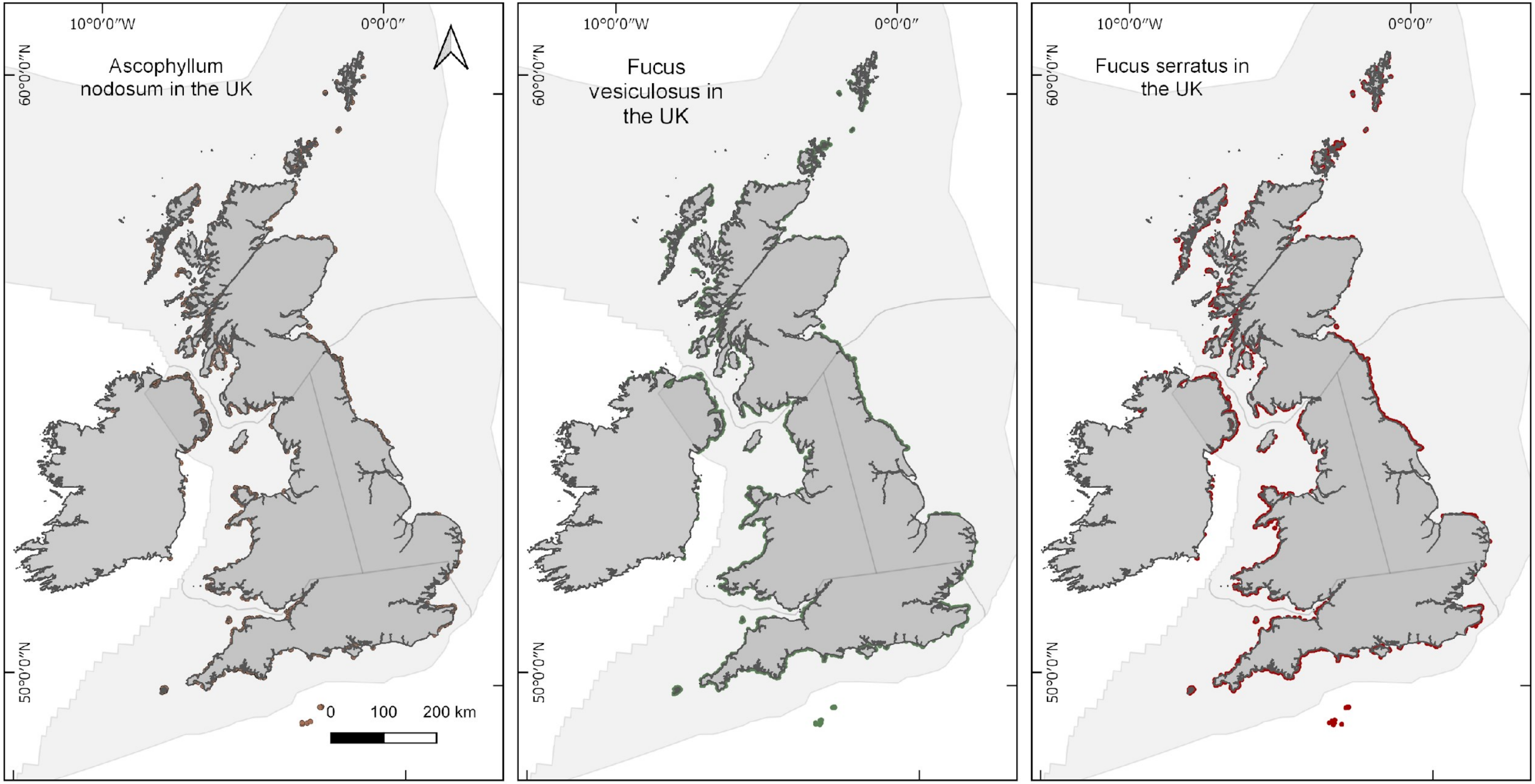

Figure 10. Distribution of point-source records for three intertidal seaweeds across the UK, based on the Archive for Marine Species and Habitats Data (an open source available from DASSH at www.dassh.ac.uk).

2.2.6 Seagrass

The seagrass meadows in the UK are dominated by three species. Two belong to a relatively small genus (*Zostera*) of marine flowering vascular plants (angiosperms) in the family Zosteraceae, and the third species is *Ruppia maritima* from the family Ruppiaceae. The genus *Zostera* is characterised by monopodial (upward growing, single stemmed) creeping interconnected rhizomes, and is monoecious (i.e., it has both male and female reproductive organs).

Zostera marina, also known as common eelgrass, is a widespread seagrass species that can survive at greater depths than its relative, *Zostera noltii*. It is the dominant seagrass species in the UK, and is also common in the northwest Pacific, the USA and Europe. *Z. marina* has larger leaf blades (usually 5–10 mm wide) and generally forms denser cover than *Z. noltii*, but its morphology can vary depending on environmental factors (Dennison and Alberte, 1986; La Nafie *et al*., 2012; Potouroglou *et al*., 2017; Green *et al*., 2018).

Z. noltii, commonly known as dwarf eelgrass, is a desiccation-tolerant species usually found between mean high water and mean low water, and rarely below the low water mark. The blades of this species are much narrower than those of *Z. marina*, rarely exceeding 2–3 mm, and are also considerably shorter than those of *Z. marina* (Jiménez *et al*., 1987; Harrison, 1993), typically reaching 15–20 cm (Peralta *et al*., 2005), whereas those of *Z. marina* grow up to 50–60 cm in length (Jacobs, 1979).

Other species in the UK include *Zostera angustifolia* (narrow-leaved eelgrass) and *Ruppia maritima* (beaked tasselweed), though the latter is not a true seagrass. There is some debate about the taxonomic status of *Z. angustifolia*, as it shows some morphological similarities to *Z. marina*, and it is therefore often referred to as *Z. marina* var. *angustifolia* (den Hartog, 1972; Provan *et al*., 2008). The defining feature of *R. maritima* is that it is a short and non-coiled pedunculate species (Ito *et al*., 2017). The plant has slender branched stems, its leaves are 2–10 cm in length and it grows in soft sediments in sheltered shallow areas. Neither *Z. angustifolia* nor *R. maritima* are thought to be distributed extensively throughout the UK.

Seagrass meadows provide multiple ecosystem services, including biodiversity enhancement, coastal protection, water oxygenation, sediment stabilisation, nutrient remediation and carbon storage. Through sediment stabilisation, seagrass is thought to protect sediment carbon stores beneath the meadow for extended periods. Seagrass contributes to sediment stores by trapping particulate carbon among roots originating from remote sources (i.e., allochthonous in origin) and from the seagrass plants themselves (autochthonous in origin; Potouroglou, 2017). There are limited UK studies that discuss in detail the complexities of sediment carbon dynamics beneath seagrass beds. The storage rate of 100.4 g C/m²/yr used in the present study is a conservative estimate derived from observations throughout the UK (Burrows *et al*., 2014; Garrard and Beaumont, 2014; Jones and Unsworth, 2016; Potouroglou *et al*., 2017; Green *et al*., 2018, 2021).

Figure 11. Currently mapped extent of seagrass (both subtidal and intertidal species) within the study areas highlighted in green (not to scale). Shapefile data are merged from Scotland (GeMS habitat polygon database), England and Wales (Environment Agency data), the Isle of Man Manx Blue Carbon Project (personal communications) and Northern Ireland Government data (www.opendatani.gov.uk). The total area of known (currently mapped) seagrass beds is 73.6 km^2, which is less than 0.01% of the total area of the UK's seas.

2.2.7 Maerl

Maerl is a term that covers calcareous coralline red algae that exist unattached in often deep beds in mixed or coarse sediment on open coastlines (Hall-Spencer *et al*., 2010). Maerl in the UK consists of *Lithothamnion glaciale*, *Phymatolithon calcareum* and a recently discovered species, *Lithothamnion erinaceum* (Melbourne *et al*., 2017). *Lithothamnion soriferum* is also present on Scottish and Irish coasts (Melbourne *et al*., 2023).

As with kelp forests, water clarity determines the depth to which maerl beds are found. An earlier review (Burrows *et al*., 2014) estimated that there were 7.5 km^2 of maerl beds in Scotland, but the most recent data on maerl in Scotland (NatureScot GEMS V10 i26 dataset, 2023) records a larger area (31.4 km^2, and an even greater area when mixed with *Modiolus* beds; see Table 4), mostly around the west coast and around Orkney and Shetland (see Figure 12). Maerl is also present in Northern Ireland, the Isle of Man and along the coast of the western English Channel (see Figure 12c). As most maerl beds across the UK have not yet been mapped, the exact extent of this habitat is unknown, but is likely to be much less than the areas of other coastal vegetated blue carbon habitats.

The main role of maerl in carbon terms is as an accumulator of IC through calcification, which (as has been pointed out by Frankignoulle *et al*., 1994) is a source of CO_2 in the ocean and therefore does not make a positive contribution to carbon mitigation, with implications for policy (Turrell *et al*., 2023). As well as the large quantities of IC stored in their carbonate skeletons, the complex matrix-like structure of maerl beds means that this habitat is a store for particulate organic material. In Loch Sween in the west of Scotland, for example, maerl beds have been found to contain 720 g C/m^2 of OC in the top 25 cm of deposits (Mao *et al*., 2020), giving a total store of OC of 22,600 t C across the 31.4 km^2 of such beds in Scotland.

Maerl may not serve well as an OC store in the future due to its potential sensitivity to ocean acidification as a calcifying species (Raven, 2018) and its sensitivity to excessive sedimentation (Hall-Spencer *et al*., 2010; Joshi and Farrell, 2020).

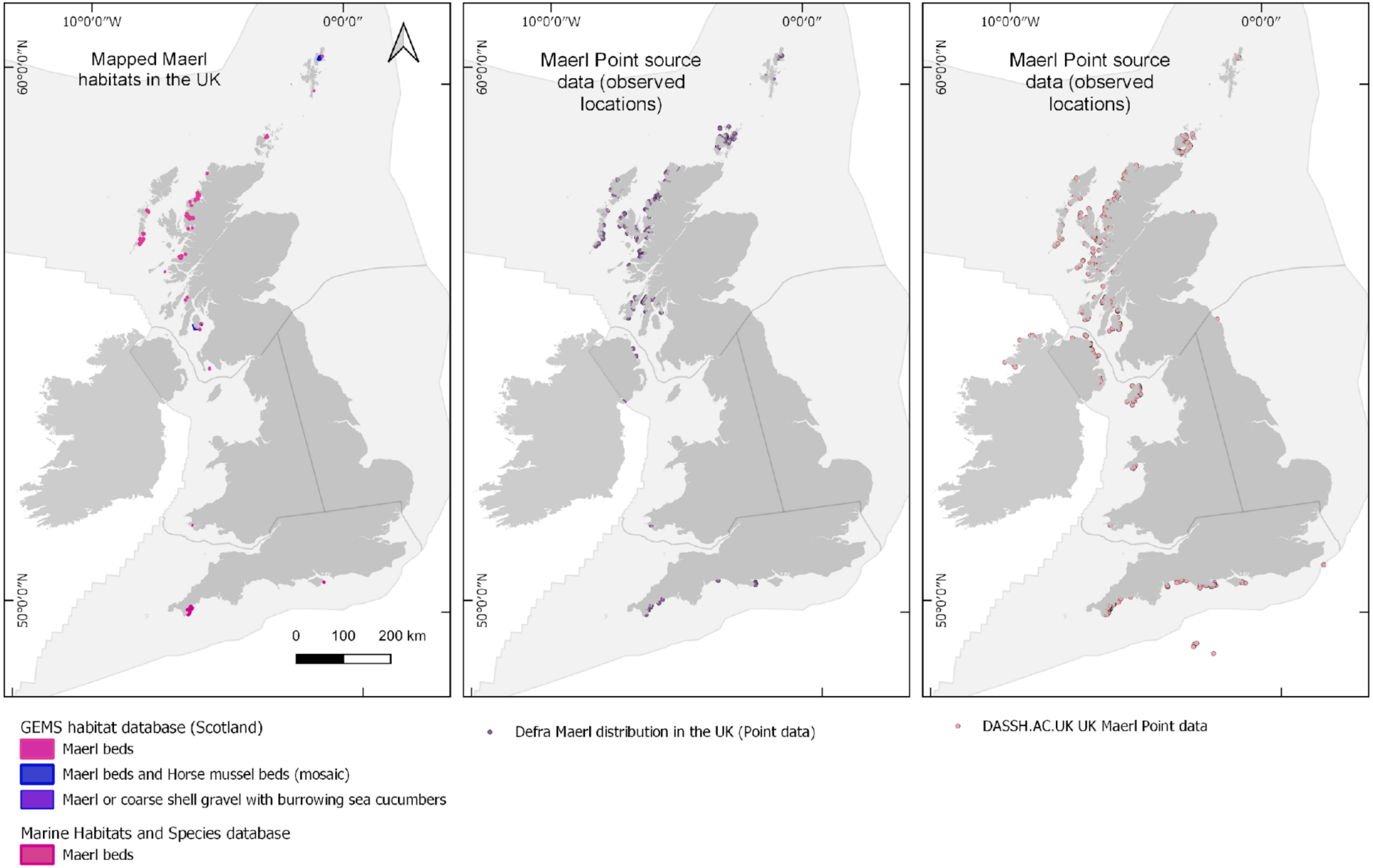

Figure 12. Current distribution of maerl habitats around the UK: (a) mapped areas of extensive beds; (b) point-source-derived data from Joint Nature Conservation Committee (JNCC) databases; (c) observed locations of maerl using data from a combination of citizen science and surveys by various agencies.

3 Carbon Stores and Accumulation Rates in UK Marine Protected Areas

Once the effect of double-counting introduced by overlapping designations has been removed (see Figure 13), the set of marine protected areas in UK and Isle of Man Territorial Seas (see Table 1), covers 27% of the English Channel and Western Approaches (ECWA) Region, 34% of the Scotland Region, 50% of the Irish Sea and Welsh Coast Region and 52% of the English North Sea Region.

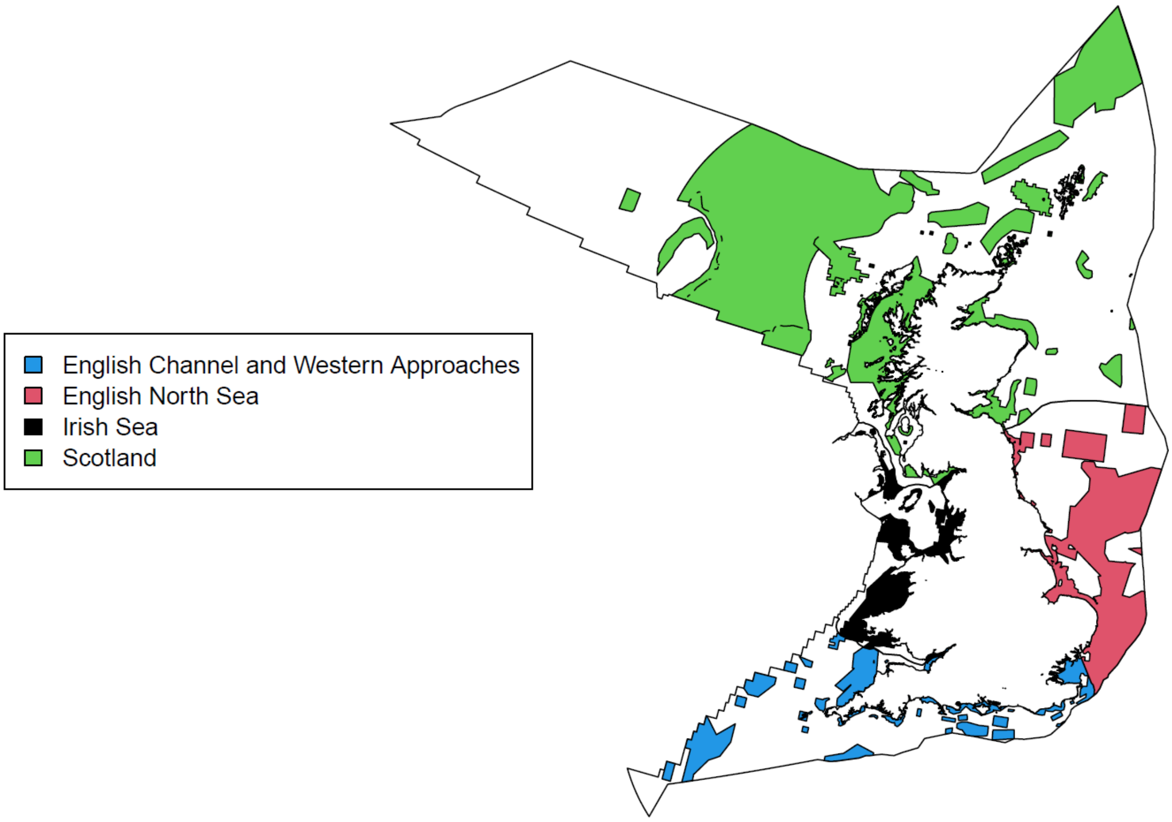

Figure 13. Areas covered by all types of MPA designations across the four blue carbon Regions in this study. Shapes show overlapping areas of MCZs, MPAs (in Scotland), MNRs, SACs and SPAs. SSSIs and ASSIs are not included but are generally small, coastal and make up less than 1% of the total area in each Region.

3.1 Habitat extents within MPAs of the UK

Different habitat types characterise the different types of marine protected area across the UK and Isle of Man blue carbon Regions. MPAs in Scotland have the greatest extent and percentage area of deep sediment habitats (see Figure 14, and Figure18 for overlapping designations), followed by SACs, with other types (MCZs in England and Wales, MNRs in the Isle of Man, and SACs and SPAs in all devolved administrations) including mostly sublittoral sediment. SSSIs (and ASSIs in Northern Ireland) differ from the other types in being focused on areas close inshore, with a much higher proportion of intertidal sediments and biogenic habitats (primarily saltmarshes). Despite only being present in waters around Scotland, MPAs (also known as Nature Conservation MPAs) cover a far greater area than that covered by the other types of designation.

Specific habitat composition of the different protected area types obviously reflects their geographical location, with the large offshore MPAs in Scotland having the most deep-sea sediment types (see Figure 15) and SSSIs with the highest proportion of littoral seabed types. Seabed type composition across protected areas drives their estimated rates of OC accumulation, with those protected area types with a larger area of littoral and sublittoral mud having higher rates of estimated OC accumulation (see Section 3.3).

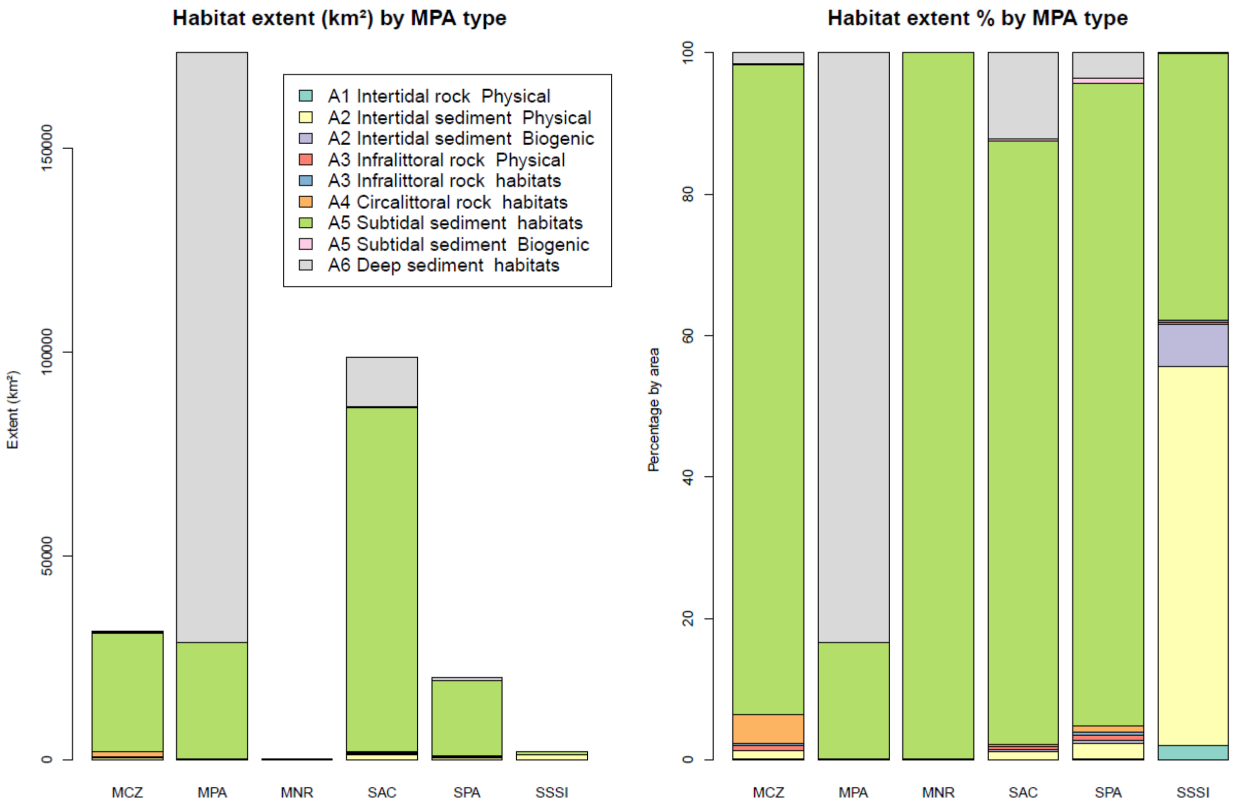

Figure 14. Broad classes of constituent habitats in different types of marine protected areas across the four study Regions.

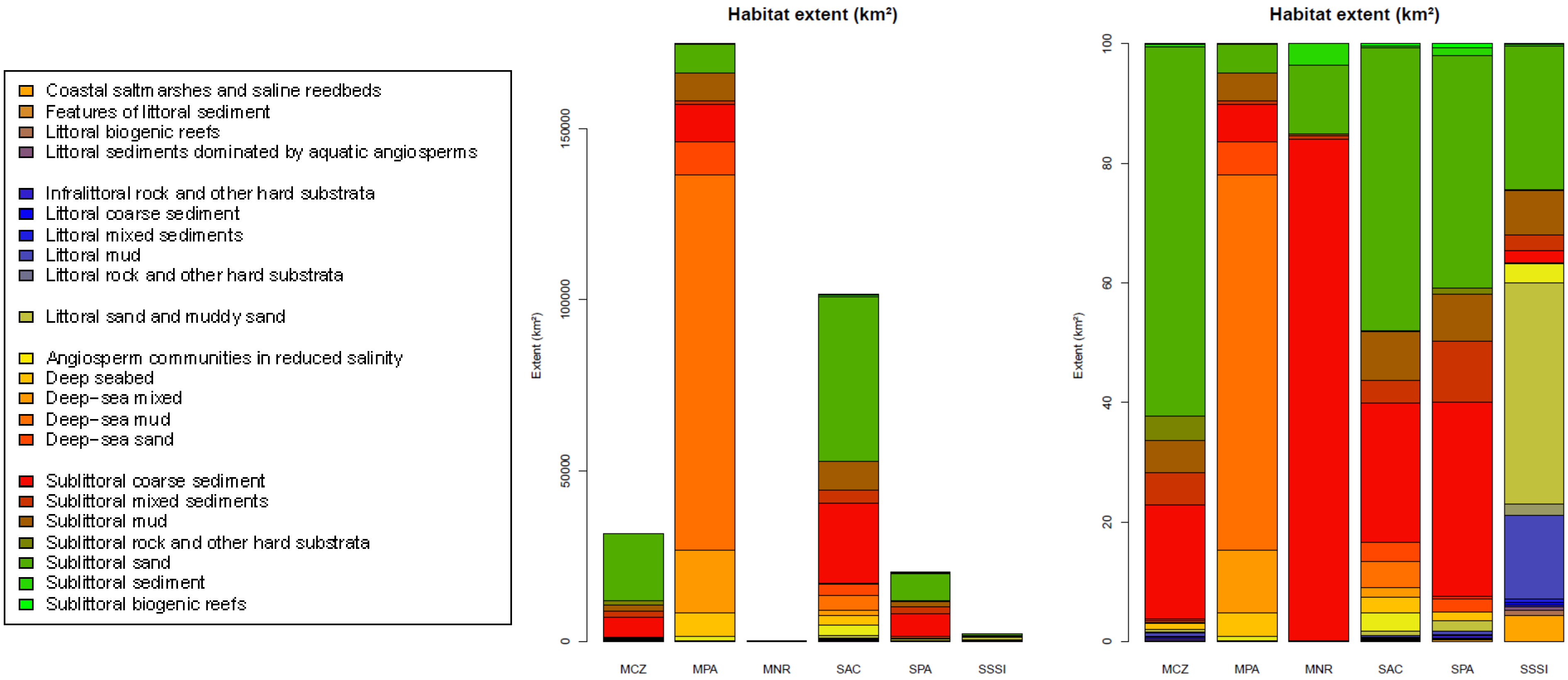

Figure 15. Detailed composition of seabed habitats among different types of marine protected areas in UK seas (including the Isle of Man Territorial Seas).

3.2 Stored carbon in the MPAs of the UK and the Isle of Man Territorial Seas

Organic carbon stored in the top 10 cm of sediment in marine protected areas was evaluated by multiplying the average carbon density (see Figure 2) inside the area boundaries by their total extent. SSSIs and ASSIs (see Figure 16a) are smaller but have more variable OC densities, as they span areas with rocky habitats with lower carbon densities as well as organically rich inshore muddy areas. Designated areas show no clear pattern of carbon density among the different types (see Figure 16a). It might be expected that marine protected areas with mostly mud habitats would have higher OC densities (expressed as g C/m^2), but no clear differences emerged between protected areas based on their most extensive habitat type (see Figure 16b). Average sediment OC in designated areas was similar among the four Regions (see Figure 16c).

The main driver of differences in carbon stored in designated areas was their extent (see Figure 17), with SSSIs storing the least carbon, and MPAs and MCZs storing the most OC.

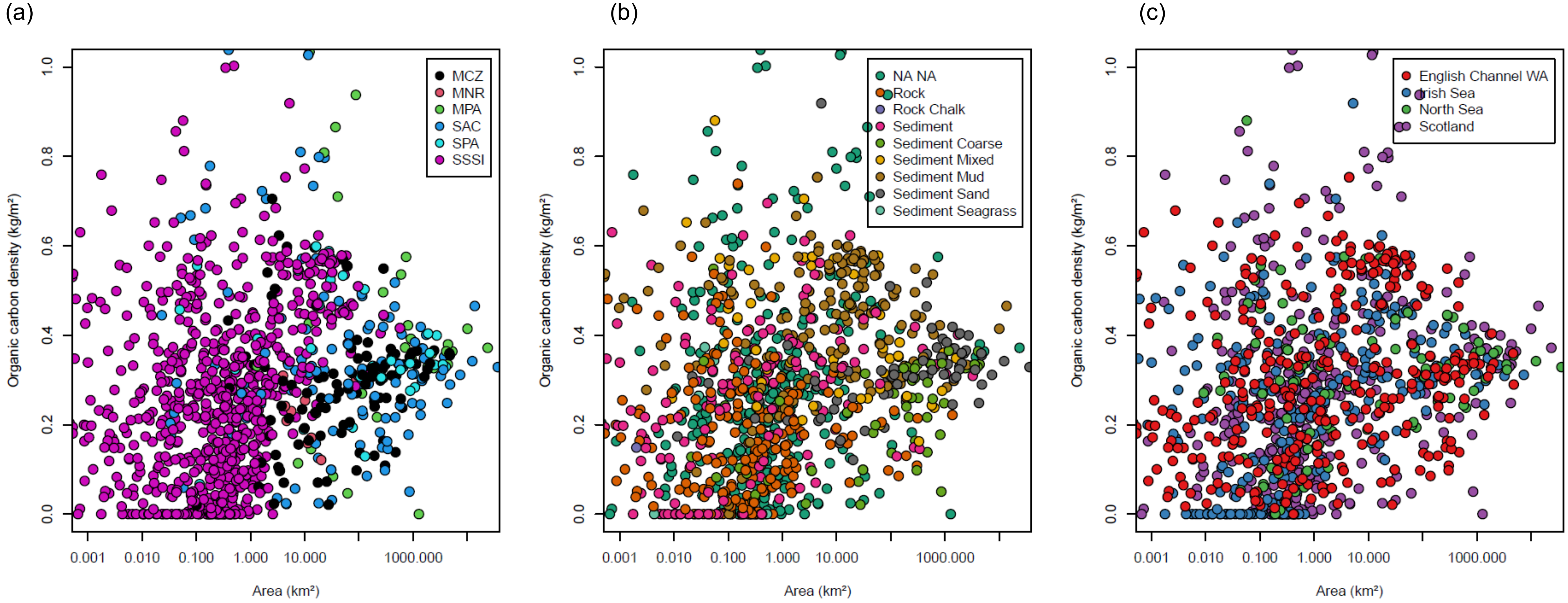

Figure 16. Organic carbon density (average value in kg/m^2) versus area (km^2) for 1,141 marine protected areas in UK and Isle of Man Territorial Seas (111 MCZs, 11 MNRs, 37 MPAs, 146 SACs, 54 SPAs and 782 SSSIs). Symbols show (a) MPA type, (b) the most extensive habitat type in each area ("NA NA" indicates that there are no data) and (c) assessment Region (see Figure 13).

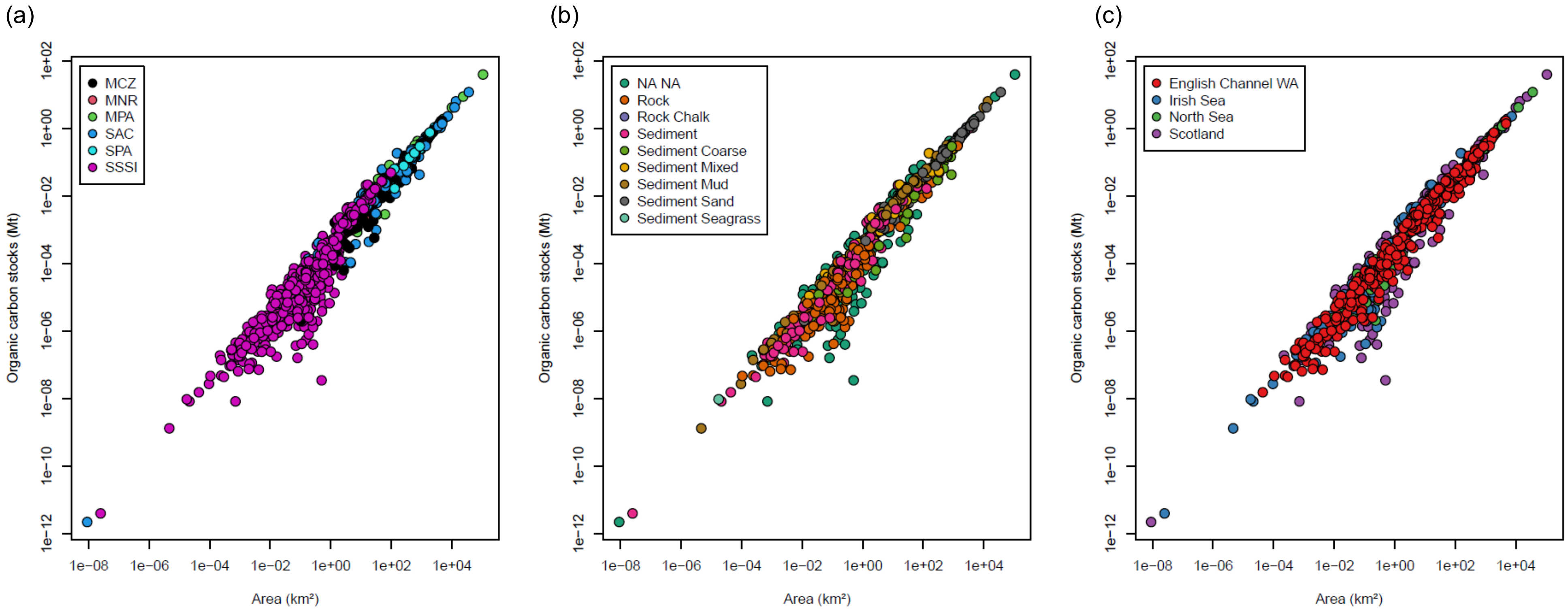

Figure 17. Organic carbon in long-term stores (Mt) versus area (km^2) for 1,141 marine protected areas in UK and Isle of Man Territorial Seas (111 MCZs, 11 MNRs, 37 MPAs, 146 SACs, 54 SPAs and 782 SSSIs). Symbols show (a) MPA type, (b) the most extensive habitat type in each area ("NA NA" indicates that there are no data) and (c) assessment Region (see Figure 13).

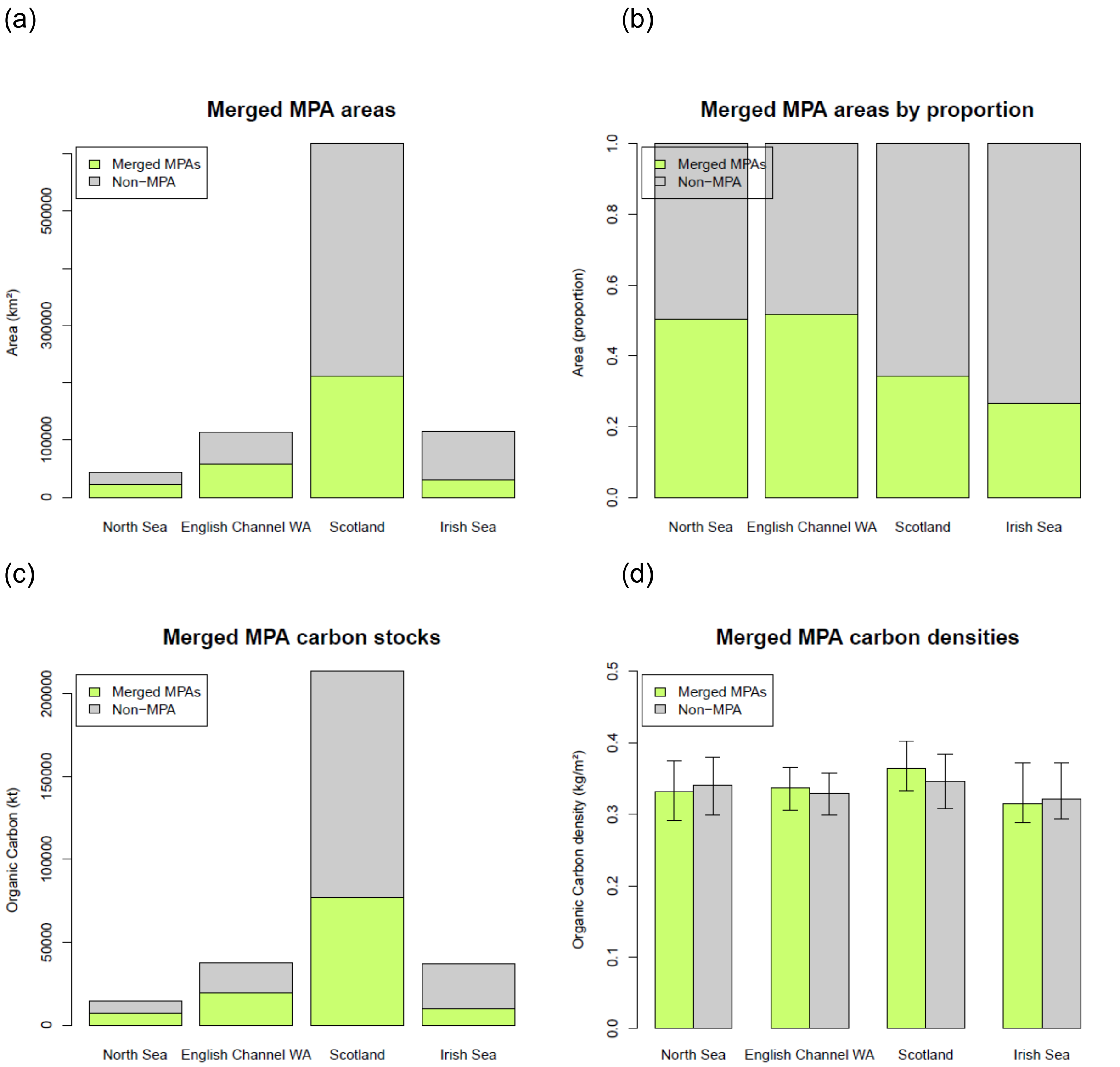

Figure 18. Areas and carbon in long-term stores covered by overlapping marine protected area designations (MCZs, MPAs in Scotland, MNRs, SACs and SPAs as shown in Figure 13, excluding SSSIs and ASSIs) in each blue carbon Region. (a) Regional and overlapping MPA extent (km²). (b) Proportions of area within designated marine protected areas by Region. (c) Total sediment organic carbon in long-term stores (kt, less than 0.1 m depth) across Regions inside and outside marine protected areas. (d) Average density of organic carbon inside and outside marine protected areas across Regions. Error bars show 25% and 75% quantile values.

3.3 Rates of carbon accumulation across the MPAs of the UK and the Isle of Man Territorial Seas

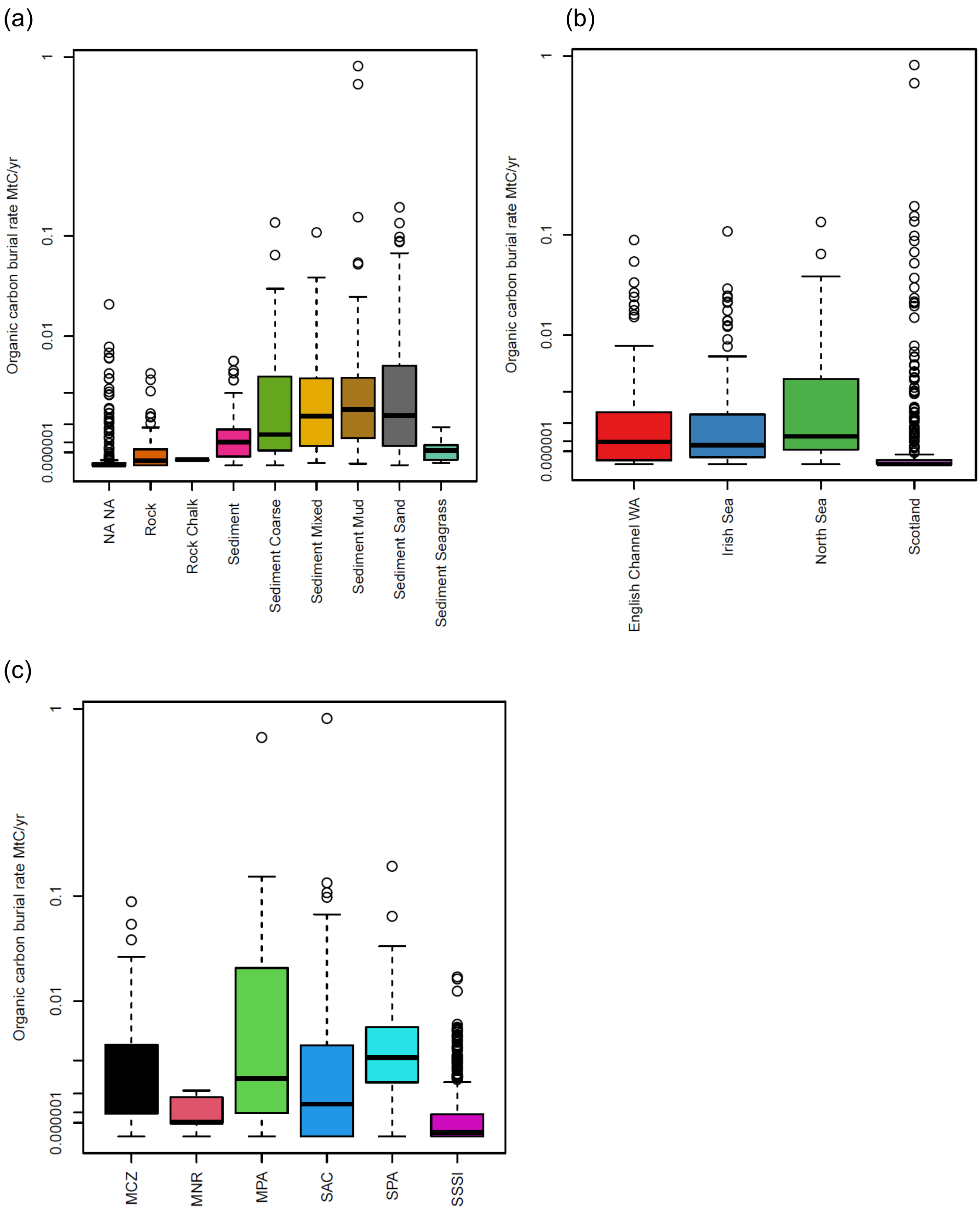

Figure 19. Organic carbon accumulation rates (Mt) for 1,141 marine protected areas in UK and Isle of Man Territorial Seas (111 MCZs, 11 MNRs, 37 MPAs, 146 SACs, 54 SPAs and 782 SSSIs). Box plots show the distribution of values by (a) the most extensive habitat type in each area, (b) assessment Region and (c) MPA type. "NA NA" indicates protected areas that lack habitat information.

Area-specific rates of OC accumulation in sediments in designated areas were obtained using habitat-specific accumulation rates for component habitats and summed across the within-MPA habitat extents to obtain the values presented here.

Rates of accumulation of OC among designated areas (see Figure 19c), like those for long-term stores, followed differences in extents between the different types of area, with individual SSSIs storing the least carbon each year, followed by MNRs, MPAs, SACs and MCZs, with SPAs storing the most carbon. The dominant habitat type in each designated area (see Figure 19a) influenced accumulation rates as expected. The marine protected areas with high OC density tended to be those with the highest estimated carbon accumulation rate (see Figure 19a). This association was expected, as the latter measure was driven strongly by the presence of rapidly accumulating mud habitats in each MPA. The small amount of carbon stored annually in designated areas where seagrass was the dominant habitat was due to the small extent of such places (see Figure 19a, far right vertical bar).

4 Ecosystem-Scale Carbon Budget

4.1 Organic carbon

Summarising the dynamics of carbon in long-term stores (see Section 2.2.1 and Table 3) across the blue carbon habitats considered here, from seafloor sediments to saltmarshes, shows the relative importance of each component (see Section 2.1.3). Although some elements remain unknown, these values demonstrate the overriding importance of phytoplankton and sublittoral sediments as the primary carbon source and carbon store, respectively, in the Region.

Depicting the transport and exchange of OC among coastal vegetated blue carbon habitats, pools of suspended particulate organic carbon (POC) and sediment stores diagrammatically (see Figures 20 and 21) shows more clearly the relative contributions of each source and store of carbon. Coastal vegetated blue carbon habitats (see Figure 20) supply less than 5% of the OC contributed by phytoplankton to the POC pool. Using a high value for rates of OC storage (see Section 4.1.2), a smaller proportion of the POC produced each year is stored in coastal vegetated blue carbon habitats (see Figure 21) than in seabed sediments. Most OC is accumulated annually in sublittoral mud (see Figure 21), but there is considerable uncertainty about the value of 13.6 Mt C/yr for this habitat. Recent studies (Diesing *et al*., 2021) suggest that, beyond areas of rapid sedimentation in fjordic environments (Smeaton *et al*., 2017), OC accumulation is much slower in offshore mud habitats, and the total quantity stored may be just 89,000 t C/yr (see Section 4.1.2 and Figure 25).

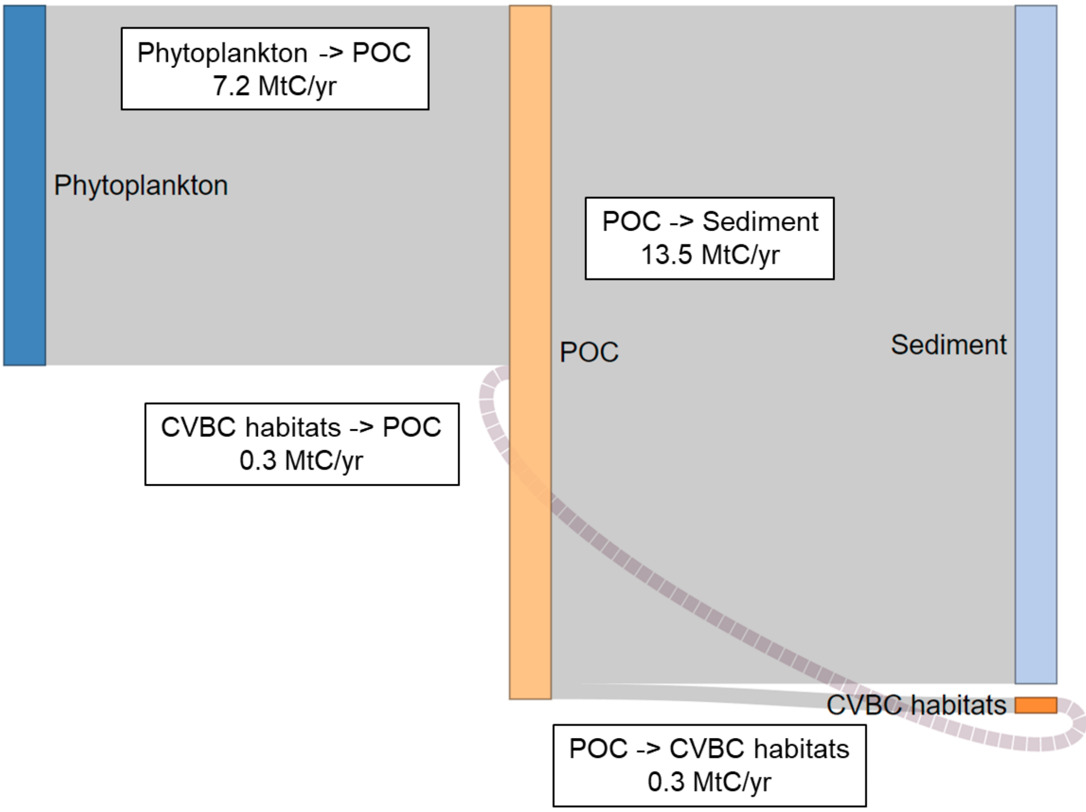

Figure 20. Annual flows of organic carbon from sources to stores summed over all four Regions studied, based on values presented in Table 3, and shown as a Sankey diagram with flows from left to right. The heights of each block represent the flows into and out of each carbon source or sink. POC, particulate organic carbon; CVBC: coastal vegetated blue carbon.

Inspection of the flow diagrams shown in Figures 20 and 21 also highlights a mismatch between the estimated amount of POC produced each year from phytoplankton and coastal vegetation, based on the productivity and extent of these habitats, and the estimated quantity of OC added to the sediment stores. This discrepancy could have several potential drivers: (1) underestimation of OC production from phytoplankton and coastal vegetation; (2) overestimation of sediment OC accumulation; (3) a ‘missing source’ of particulate matter, such as riverine inputs; or (4) uncertainty in estimates of production and accumulation. The last of these seems to be the most immediately credible reason, especially given the range of values for sediment carbon storage generated by simple simulations based on parameter uncertainty (see Section 4.1.1).

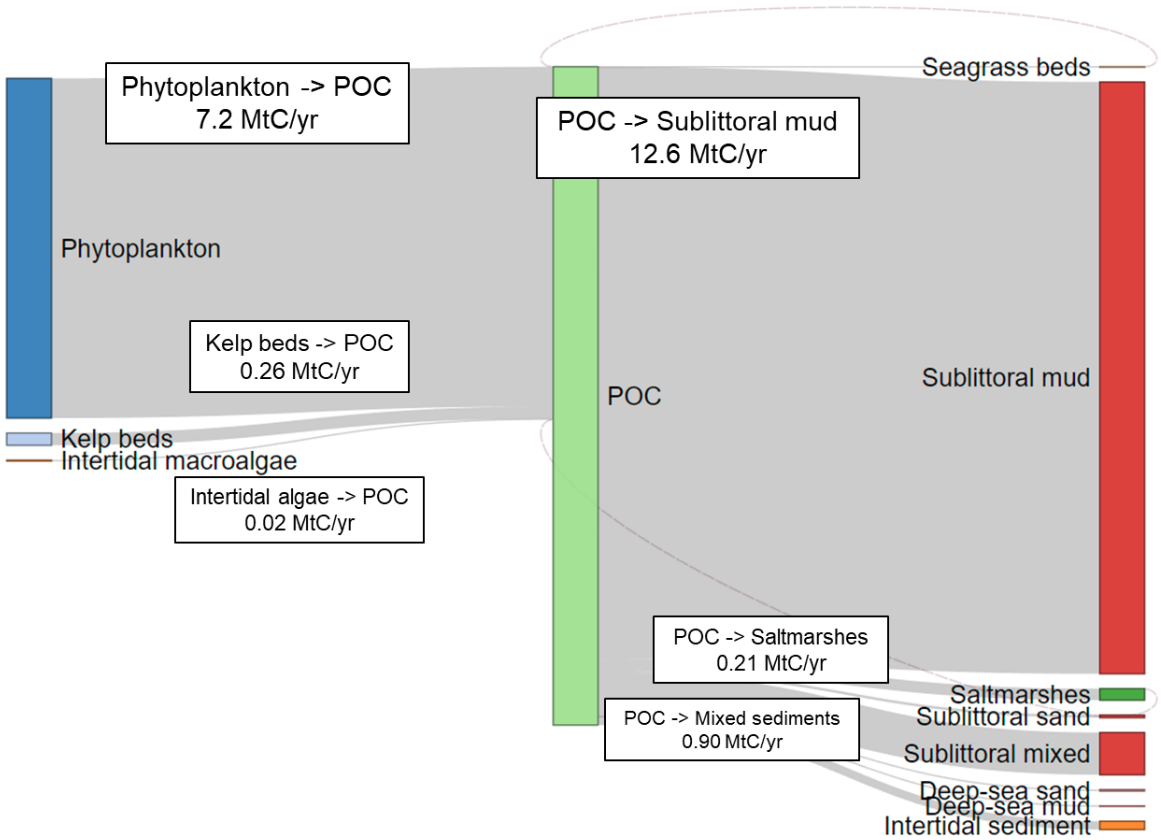

Figure 21. A detailed breakdown of annual flows of organic carbon from sources to stores summed over all four study Regions, based on values presented in Table 4 with flows from left to right. The heights of each block represent the flows into and out of each carbon source or sink, with the particulate organic carbon (POC) added to stores annually calculated from literature values for storage rates for each habitat.

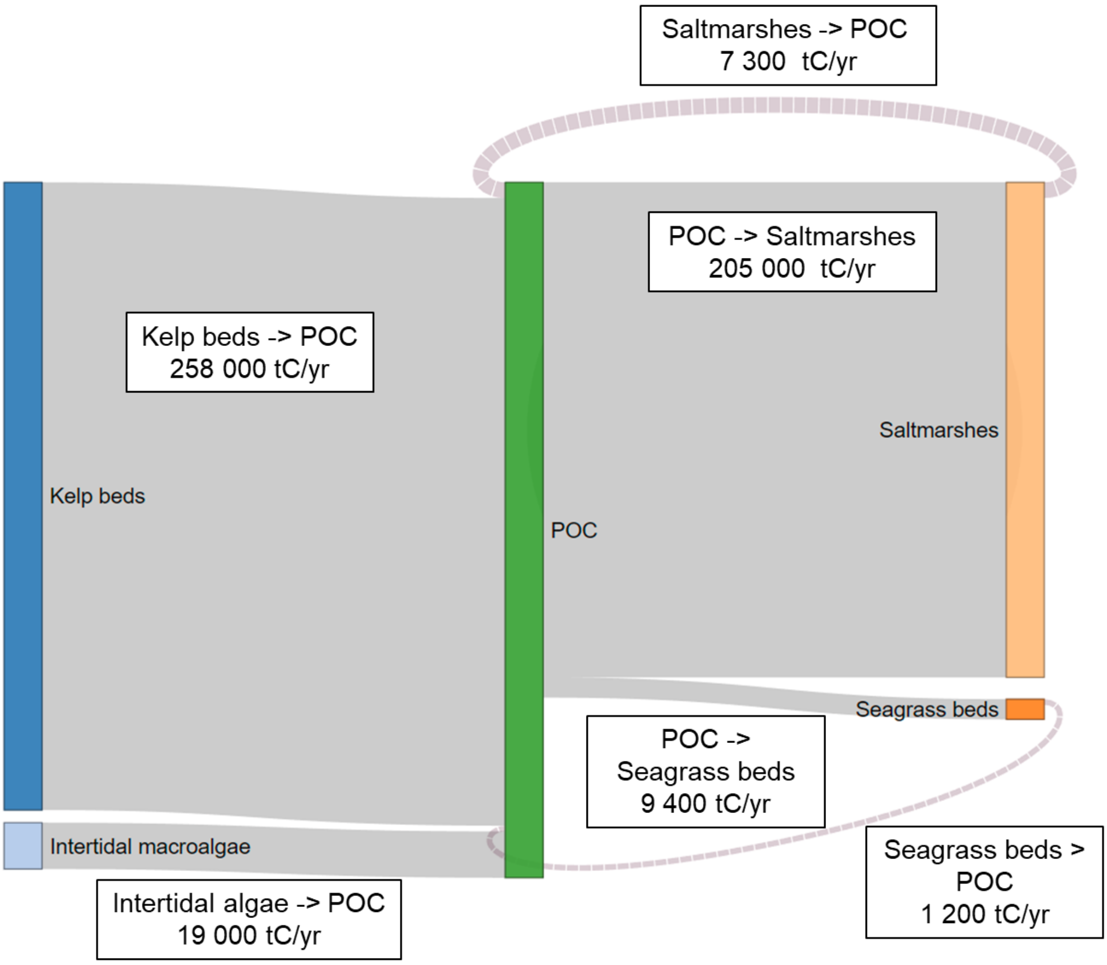

Figure 22. Organic carbon flows in the coastal vegetated blue carbon habitats of the UK and Isle of Man Territorial Seas.

The overwhelming dominance of primary production by phytoplankton as a source of OC and of marine sediment as stores of OC tends to obscure the role of coastal vegetated blue carbon habitats in the UK's seas. Excluding these dominant sources and sinks clarifies the relative contributions of places traditionally viewed as blue carbon habitats (see Figure 22). Of these habitats, subtidal kelp contributes the most particulate material (as POC) to the marine environment, followed by intertidal macroalgae, saltmarshes and seagrass beds in that order (see Figure 22).

4.1.1 Uncertainty about total UK organic carbon accumulation rate due to parameter uncertainty

Estimates of the total quantity of OC stored in sediments annually are strongly dependent on the values used for carbon accumulation rates for each habitat type. These rates have been derived from reviews of the literature and have been presented in each of the regional reports. Here the effects of uncertainty about accumulation rates on the estimated total can be seen using the results of a Monte Carlo simulation. Carbon accumulation rates for each habitat were randomly selected multiple times (n = 5,000) from Gaussian distributions of values representing the uncertainty for each rate. Gaussian distributions used the mean values adopted throughout this series of reports, and standard deviations obtained from minimum and maximum values in the literature reviews (assuming that minima and maxima represent the 5th and 95th percentiles of the Gaussian distributions, respectively).

The distribution of estimates for total OC stored each year from these simulations (see Figure 23) shows the effect of uncertainty in carbon accumulation estimates. Since most stored OC is in sublittoral mud (see Figure 21), the distribution of estimates for this habitat alone (denoted by brown bars) closely matches that of the total (denoted by grey bars).

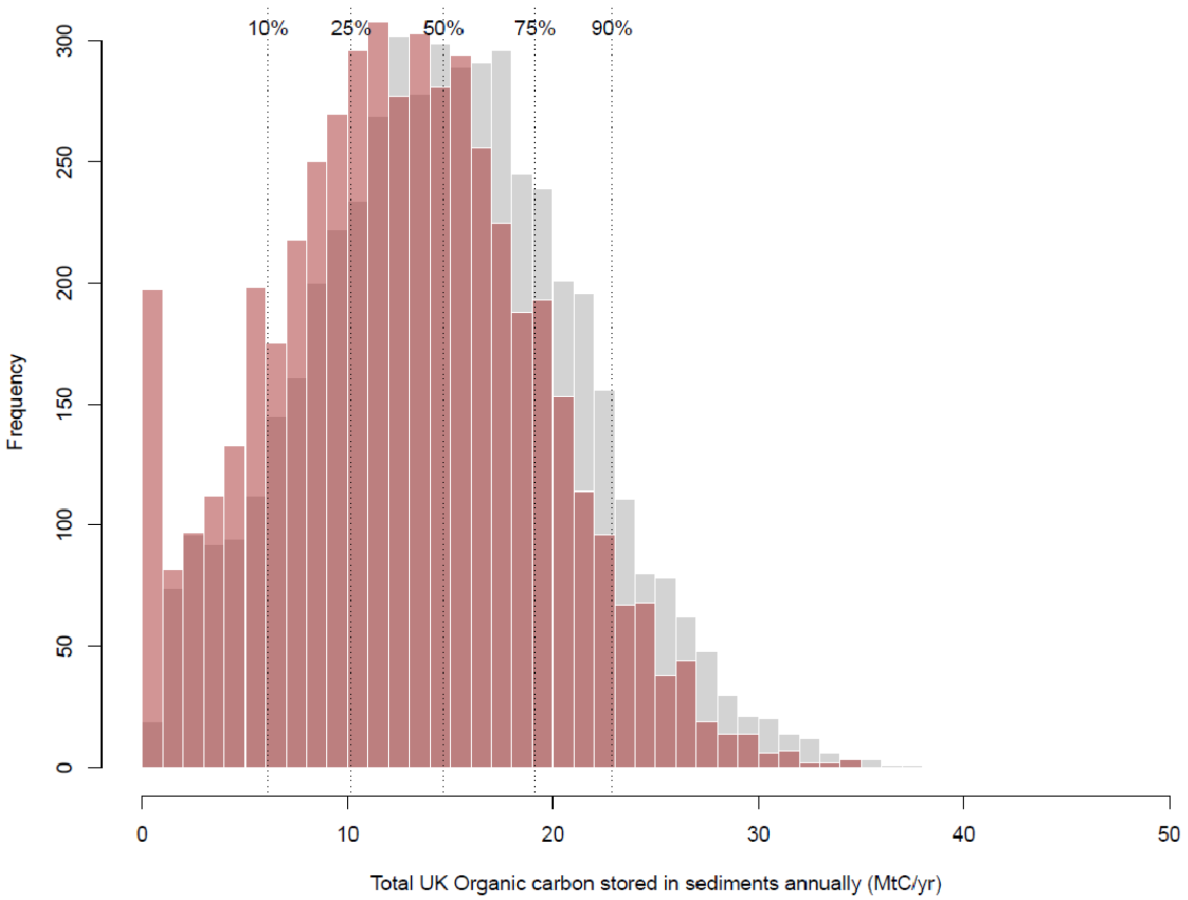

Figure 23. Uncertainty with regard to the UK and Isle of Man Territorial Seas's organic carbon totals added annually to sediment stores (Mt C/yr) from Monte Carlo simulations of carbon budgets. Frequencies of total values are represented by grey bars, with brown bars denoting the totals across sublittoral mud habitats, and darker brown areas indicating where the grey and brown bars overlap. Vertical broken lines show quantiles of the distribution of estimates for total carbon sequestered (median value is 14.7 Mt C/yr).

4.1.2 Overestimation of organic carbon accumulation rate in sublittoral mud

The rates of OC accumulation in sublittoral mud that were initially used in this study (minimum, 18.7 g C/m^2/yr; maximum, 291.6 g C/m^2/yr; mean, 155.2 g C/m^2/yr) came from a review of literature values by Burrows *et al*. (2014) (see Table 11 in Burrows *et al*., 2024c) covering fjordic and shelf muds. Relatively few of these values were from UK waters, but they did include studies from the Skagerrak, with reported values of 130 g C/m^2/yr (Jørgensen *et al*., 1990) and 30–150 g C/m^2/yr (Anton *et al*., 1993), and a study from Canada with reported values of 18.7–291.6 g C/m^2/yr (St-Onge and Hillaire-Marcel, 2001). Accumulation rates for mud habitats from UK studies included estimates from fjordic sea lochs on the west coast of Scotland, namely Loch Linnhe, with a value of 146 g C/m^2/yr (Overnell and Young, 1995), and Loch Creran, with a value of 91.3 g C/m^2/yr (Loh *et al*., 2010). These values are not dissimilar to the single mean value used in the present study, but their mean is not representative of realised OC accumulation rates across the UK's EEZ. A recent exploration study of the North Sea highlighted that many areas experience close to zero OC accumulation, and northern parts of the North Sea experience OC accumulation rates of less than 20 g C/m^2/yr (Diesing *et al.*, 2021). These low OC accumulation rates are further supported by de Haas *et al.* (1997), who estimated that the North Sea accumulates 1,000,000 tonnes of OC annually, which equates to *c*. 18.5 g C/m^2/yr. Rates of accumulation predicted from the study by Diesing *et al.* (2021) are linked to sediment types (see Figure 24) with, as expected, higher rates in mud habitats and lower rates in sand and coarse sediment habitats. However, predicted accumulation rates from Diesing *et al.* (2021) (see Figure 24) are nearly two orders of magnitude smaller than the values used in the analysis presented here. The typical maximum of 4 g C/m^2/yr for the sublittoral mud habitats in the Scotland Region from data shown in Figure 24 is only 3% of the value of 155 g C/m^2/yr used so far in this analysis, and is much closer to the literature values used here for sublittoral sand (0.2 g C/m^2/yr). Using average OC accumulation rates for the Scottish Region, part of Diesing's dataset (0.63 g C/m^2/yr) gives a total annual accumulation of 79,200 t C/yr from a subset of 20% (126,000 km^2) of the Region; this is just 0.8% of the 9.5 Mt/yr total estimated from the larger value for accumulation in sublittoral mud. The discrepancy between these two estimates, combined with the absence of experimental measurements, confers considerable uncertainty on the value for annual OC accumulation in the Region. A review by Parker *et al.* (2021) for Secretary of State waters, covering all but the Scotland Region, reported a higher value (29.5 g C/m^2/yr) for OC accumulation in subtidal mud, intermediate between the very low and very high values discussed here.

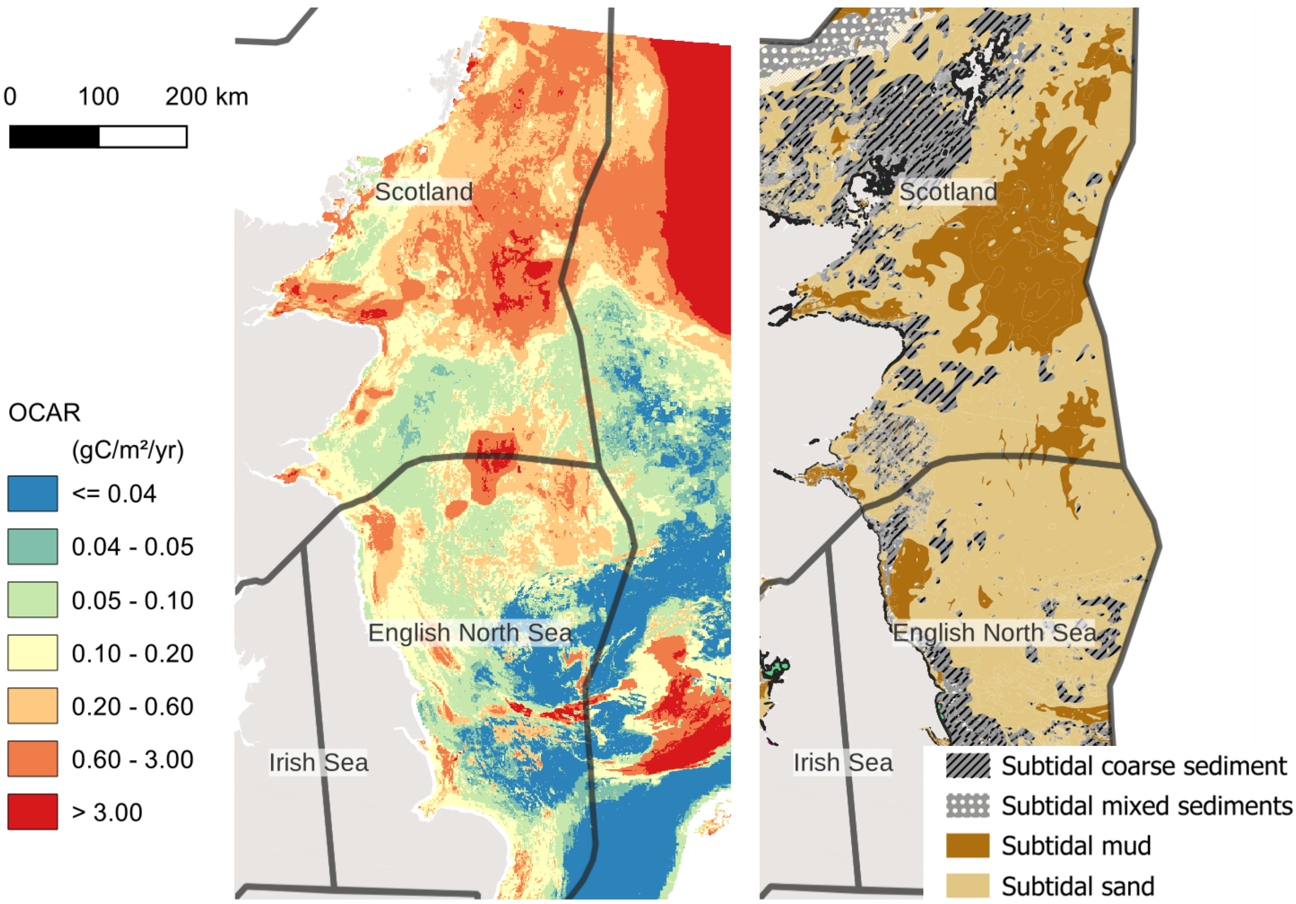

Figure 24. (left) Sediment organic carbon accumulation rates in the North Sea, from Diesing et al. (2021); (right) EUSeaMap habitat types.

A more recent study (Smeaton *et al.*, 2021c) estimated OC accumulation rates in Scottish fjords to be 57.1 ± 10.9 g C/m^2/yr, much lower than the rate used here (155.2 g C/m^2/yr) applied more widely to all sublittoral muds. Given that fjords are identified as hotspots for carbon accumulation both globally and nationally (Smith *et al.*, 2015; Smeaton *et al.*, 2017), it seems likely that the estimate for carbon accumulation rate in fjords is an upper limit for rates of accumulation more generally in sublittoral muds. The resulting overestimate of OC accumulation in mud sediments reverses the apparent discrepancy between the rate of delivery of OC from phytoplankton and coastal vegetation to sediments (see Figure 21; 7.1 Mt C/yr as 10% of primary production delivered to sediments) and the estimated total buried in sediments (13.6 Mt C/yr using the higher estimated OC accumulation rate). If accumulation of OC in sublittoral mud is much less than was originally assumed, much more organic detritus is produced annually than is accumulated in sediments (see Figure 25). Diesing *et al.* (2021) showed that the Norwegian Trough (red area in top right corner of the left-hand map in Figure 24) was the most important centre for OC deposition in the area. This suggests that, outside of the coastal vegetated blue carbon habitats, much of the OC fixed by phytoplankton may end up stored outside the UK region.

This stark difference between assumed values for OC accumulation requires a re-evaluation of the relative quantities stored by different habitats each year (see Table 5 and Figure 25). Coastal vegetated blue carbon habitats become much more important as sinks for POC when using the lower rate of accumulation in sublittoral mud habitats, potentially accounting for 64% of total accumulation of OC in sediments (see Table 5).

Table 5. Revised ecosystem summary (based on Table 3) using lower rates of sediment accumulation in sublittoral mud habitats.

Region	Habitat	Extent (km^2)	Store total (Mt C) [0.1 m depth]	Store density (g C/m^2)	Production rate (g C/m^2/yr)	Total production (1,000 t C/yr)	Outflux (1,000 t C/yr)	Influx (1,000 t C/yr)	Storage rate (g C/m^2/yr)	Storage capacity (1,000 t C/yr)
Scotland	Phytoplankton	617,385			81	50,233	5,023			
	All sediment	437,883	151.8	346.8				90	0.2	90
	CVBC habitats	5,228	0.7	129.4	328	1,736	174	8	1.5	8
Irish Sea	Phytoplankton	43,112			81	3,508	351			
	All sediment	43,112	14.7	341.4				10	1.8	10
	CVBC habitats	1,800	1.2	670.5	307	549	55	119	66.2	119
English Channel and Western Approaches	Phytoplankton	111,469			81	9,069	907			
	All sediment	111,469	35.8	321.5				27	0.7	27
	CVBC habitats	1,318	0.7	503.0	315	414	42	67	51.2	67
English North Sea	Phytoplankton	113,947			81	9,271	927			
	All sediment	113,947	37.5	329.1				25	0.2	25
	CVBC habitats	584	0.8	1,299.1	285	165	17	77	131.0	77
All UK	Phytoplankton	885,913	0.0			72,081	7,208	0		0
	All sediment	706,411	239.9			0	0	153		153
	CVBC habitats	8,931	3.3			2,864	286	271		271
	Total	885,913	243.2			74,945	7,495	424		424
Percentages	Phytoplankton	100%	0%			96%	96%	0%		0%
	All sediment	99%	99%			0%	0%	36%		36%
	CVBC habitats	1.0%	1.4%			3.8%	4%	64%		64%

CVBC, coastal vegetated blue carbon.

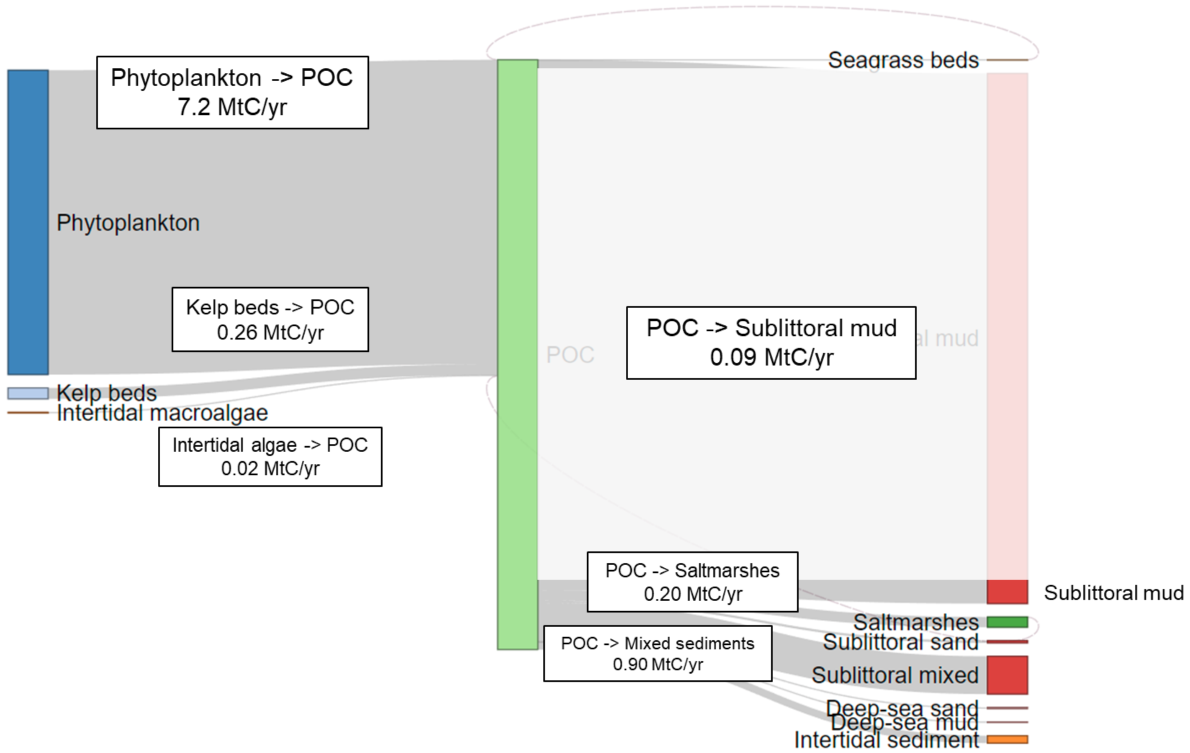

Figure 25. Organic carbon accumulation in UK seas using revised rates for sublittoral mud habitats. The quantity of OC stored in sublittoral mud is reduced from 12.6 Mt C/yr to 0.09 Mt C/yr.

Repeating the simulations of the effects of parameter uncertainty on total annual UK sediment OC accumulations using lower ranges for rates in sublittoral mud habitats (EUNIS A5.3: 0.2–2.7, 1.1 g C/m^2/yr) shows the much reduced range of estimates (see Figure 26).

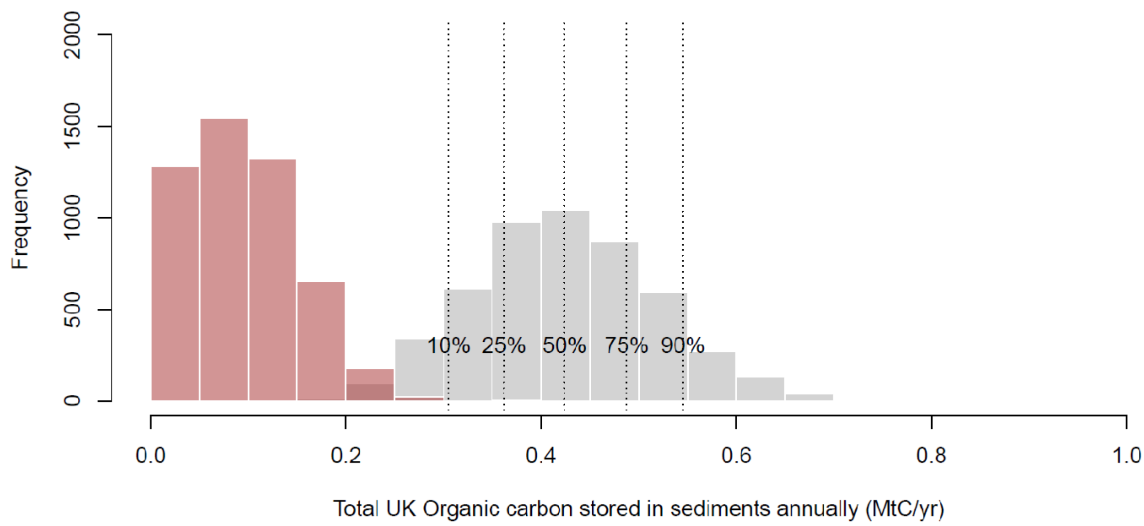

Figure 26. Uncertainty in UK organic carbon totals added annually to sediment stores (Mt C/yr) from Monte Carlo simulations of carbon budgets using rates reported by Diesing et al. *(2021). Frequencies of total values are denoted by grey bars, with brown bars representing the totals across sublittoral mud habitats, and darker brown areas indicating where the grey and brown*

bars overlap. Vertical broken lines show quantiles of the distribution of estimates for total carbon sequestered (median value is 0.42 Mt C/yr).

4.2 Inorganic carbon

Habitats rich in IC are paradoxically important when considering marine carbon in long-term stores and sequestration capacity in a climate policy context (Howard *et al*., 2017, 2023; Turrell *et al*., 2023), as they are important habitats for biodiversity but may act as both sources and sinks for carbon. The quantity of carbon stored as IC in the top 10 cm of sediments in UK seas (1,610 Mt) far exceeds the amount stored as OC (240 Mt). The majority of IC in marine habitats is in the form of calcium carbonate ($CaCO_3$) in shell material. Dissolution of calcium carbonate effectively removes dissolved CO_2 from seawater and potentially from the atmosphere (Turrell *et al*., 2023). By absorbing dissolved CO_2, the process of dissolution of calcium carbonate material can increase alkalinity and counter ocean acidification. However, the calcification process that produces the shell material which forms the bulk of this carbon store releases CO_2, and therefore cannot make a positive contribution to a greenhouse gas inventory (Frankignoulle *et al*., 1994).

Biogenic reefs formed from calcifying organisms, such as maerl, cold water corals, horse mussels (*Modiolus modiolus*), blue mussels (*Mytilus edulis*), native oysters and flame shells, release CO_2 during shell growth but may also trap OC. It this trapped OC is ultimately buried, it may potentially offset the additional CO_2 released during calcification.

In summary, Turrell *et al.* (2023) make four key recommendations in this area: (1) a clear distinction should be made between OC and IC; (2) carbon stored as $CaCO_3$ should not be seen as relevant for carbon offsetting; (3) carbon sequestration through the accumulation of shell material should always be presented alongside reports of the CO_2 released, so that the net effect is properly represented; and (4) the effect of trapped OC on biogenic reefs should not be ignored.

5 Risks to Carbon in Long-Term Stores in the UK

Multiple pressures on the existing carbon in long-term stores occur in the UK, most of which are viewed as being the result of use of the environment, or the exploitation of ecosystem services. In this section, climate change and associated impacts, and fishing are discussed. Aggregate extraction, offshore renewable energy installations and anchoring and mooring may also impact blue carbon habitats. Please see the English Channel and Western Approaches report (Burrows *et al*., 2024a) for details of these.

5.1 Climate change and associated impacts

In a changing climate, coastal habitats are at risk. There are multiple impacts, both direct (elevated temperature, more storm events) and indirect (ocean acidification, coastal erosion, turbidity), which will result in habitat loss (Burden *et al*., 2020). With the loss of habitats, the carbon storage benefits as well as other ecosystem services will be lost.

The impacts of climate change are likely to vary among habitats (Lovelock and Reef, 2020). For example, seagrass beds in Scotland are close to their geographic northern range limits. *Zostera marina* in particular is likely to be tolerant of temperature increases even under baseline emissions scenarios RCP 2.6 and RCP 8.5, and may increase in extent in more northern regions (Wilson and Lotze, 2019). Climate change is likely to bring with it additive effects. For example, elevated temperatures will probably increase algal blooms and, with these blooms, increased turbidity. Turbidity can not only reduce growth rates in seagrass but also increase susceptibility to infection with diseases that have impacts on growth and survival (Kim *et al*., 2015; Jakobsson-Thor *et al*., 2020).

Other blue carbon habitats might also see changes occur. For example, the flow of carbon through cool-water-tolerant kelp species in the north-east Atlantic may be significantly reduced by warmer climates (Pessarrodona *et al*., 2018). Changes in sea-level rise, storminess, temperature and precipitation are all likely to affect saltmarsh extent and distribution, while temperature change alone may have an impact on species composition. For example, the spread of *Spartina anglica*, a warm-tolerant invasive species which can compete with native species of cordgrass (Burden *et al*., 2020), may reduce plant diversity in saltmarsh areas, and reduced species richness is associated with loss of stability of saltmarsh soils and greater lateral erosion (Ford *et al*., 2016).

One of the overarching (top ten) pending questions that emerged from a survey of the scientific community by Macreadie *et al*. (2019) was ‘How does climate change impact carbon accumulation in mature Blue Carbon ecosystems and during their restoration?’ The answer to this question involves an understanding of how often and how intensely stressors caused by climate change occur, and how resilient or sensitive each system is to these stressors. Reducing uncertainties around the rate and magnitude of climate change stressors is also crucial to gaining a clearer understanding of how quickly and intensely climate change may affect different systems (Trisos *et al*., 2020).

5.2 Disturbance by mobile fishing gear

In the current study, the importance of OC stores in sediments is emphasised, with 240 Mt OC estimated to be stored in the top 10 cm of sediments in UK seas (see Section 2.1.1). Sediment and OC in an area of the UK’s EEZ totalling 39,335 km^2 has recently been identified to be at high or very high risk from trawling disturbance, which can potentially lead to the degradation of the sedimentary OC store (Black *et al*., 2022).

Carbon accumulation in sediment stores is mainly attributed to the production and subsequent death of phytoplankton, but other forms of detritus (e.g., kelp; see Section 2.2.4) are also contributors. The most common anthropogenic activity on the seabed is bottom trawling, which mainly targets shellfish and other commercially valuable fish for consumption (LaRowe *et al*., 2020b). Bottom trawling can penetrate the surface sediment layers to a depth of 2–16 cm, depleting biota and turning over the bioturbated sediment layer (Hiddink *et al*., 2017). There is still some debate over how much carbon is lost to remineralisation through these processes. In a first estimate, Sala *et al*. (2021) used satellite-inferred fishing information to calculate that 0.58–1.47 Pg of aqueous CO_2 were emitted per year (158–400 Mt C/yr) when sediments were turned over. In a later literature review, Epstein *et al*. (2022) addressed the uncertainties around the findings of Sala *et al*. (2021). The main causes of OC reduction in sediments include reduced production by flora and fauna, loss of precipitated (or flocculent) material, and the resuspension, mixing and transport of sediments exposed to oxygen allowing bacteria to consume OC more readily. The review found that 61% of 49 studies had reported that there would be no significant effect on carbon remineralisation by bottom trawling, 29% found that OC would be lower in sediments and 10% reported an increase in OC in sediments as a result of bottom trawling (Epstein *et al*., 2022). It has been suggested that carbon credits can be formed through the reduction of bottom trawling, thus providing a means of funding protected areas (Sala *et al*., 2021). However, a recent response to these findings suggests that much more information is needed, particularly with regard to decomposition rates (*k* values) used in sediment models (Hiddink *et al*., 2023). The debate continues, and currently centres on the reactivity of different sediment types and therefore which decomposition rates to use and how to apply them to sediments which can be vastly different (Atwood *et al*., 2023). However, all authors agree that trawling using gear that disturbs the seafloor will have a profound effect on sediment OC stores in the ocean. The exact magnitude of the effect, and what impacts trawling has on ocean acidification and on long-term carbon storage, remain uncertain.

6 References

Anton, K.K., Liebezeit, G., Rudolph, C., Wirth, H. 1993. Origin, distribution and accumulation of organic carbon in the Skagerrak. *Marine Geology* **111**, 287–297.

Arndt, S., Jørgensen, B.B., LaRowe, D.E., Middelburg, J.J., Pancost, R.D., Regnier, P. 2013. Quantifying the degradation of organic matter in marine sediments: a review and synthesis. *Earth-Science Reviews* **123**, 53–86. https://doi.org/10.1016/j.earscirev.2013.02.008

Atwood, T.B., Sala, E., Mayorga, J., Bradley, D., Cabral, R.B., Auber, A. *et al.* 2023. Reply to: Quantifying the carbon benefits of ending bottom trawling. *Nature* **617**, E3–E5.

Austin, W., Smeaton, C., Riegel, S., Ruranska, P., Miller, L. 2021. Blue carbon stock in Scottish saltmarsh soils. *Scottish Marine and Freshwater Science* **12**. https://doi.org/10.7489/12372-1

Beaumont, N.J., Jones, L., Garbutt, A., Hansom, J., Toberman, M. 2014. The value of carbon sequestration and storage in coastal habitats. *Estuarine, Coastal and Shelf Science* **137**, 32–40. http://dx.doi.org/10.1016/j.ecss.2013.11.022

Bekkby, T., Rinde, E., Erikstad, L., Bakkestuen, V. 2009. Spatial predictive distribution modelling of the kelp species *Laminaria hyperborea*. *ICES Journal of Marine Science* **66**, 2106–2115. https://doi.org/10.1093/icesjms/fsp195

Benyon, R., Barham, J., Edwards, J., Kaiser, M., Owens, S., de Rozarieux, N., *et al*. 2019. *Benyon Review Into Highly Protected Marine Areas*. https://www.gov.uk/government/publications/highly-protected-marine-areas-hpmas-review-2019

Berner, R. 2006. GEOCARBSULF: A combined model for Phanerozoic atmospheric O_2 and CO_2. *Geochimica et Cosmochimica Acta* **70**, 5653–5664. https://doi.org/10.1016/j.gca.2005.11.032

Black, K.E., Smeaton, C., Turrell, W.R., Austin, W.E.N. 2022. Assessing the potential vulnerability of sedimentary carbon stores to bottom trawling disturbance within the UK EEZ. *Frontiers in Marine Science* **9**. https://doi.org/10.3389/fmars.2022.892892

British Geological Survey. 2014. *Quaternary Deposits Thickness Dataset*. Available at https://webapps.bgs.ac.uk/services/ngdc/accessions/index.html# (accessed 22 August 2023).

Burden, A., Smeaton, C., Angus, S., Garbutt, A., Jones, L., Lewis, H. *et al*. 2020. *Impacts of climate change on coastal habitats, relevant to the coastal and marine environment around the UK*. Marine Climate Change Impacts Partnership. https://doi.org/10.14465/2020.arc11.chb

Burdige, D.J. 2007. Preservation of organic matter in marine sediments: controls, mechanisms, and an imbalance in sediment organic carbon budgets? *Chemical Reviews* **107**, 467–485. https://doi.org/10.1021/cr050347q

Burrows M.T., Hughes D.J., Austin, W.E.N., Smeaton, C., Hicks, N., Howe, J.A. *et al*. 2017. Assessment of blue carbon resources in Scotland's inshore marine protected area network. *Scottish Natural Heritage Commissioned Report No. 957.*

Burrows, M. T., Smeaton, C., Tillin, H., Grundy, S., Sugden, H., Moore, P. *et al*. 2024c. *The United Kingdom's blue carbon inventory*: *assessment of marine carbon storage and sequestration potential in Scotland (including within marine protected areas).* A report to The Wildlife Trusts, WWF and the RSPB. Scottish Association for Marine Science, Oban.

Burrows, M.T., Fox, C.J., Moore, P., Smale, D., Sotheran, I., Benson, A. *et al*. 2018. *Wild seaweed harvesting as a diversification opportunity for fishermen*. A report by SRSL for HIE. Scottish Association for Marine Science, Oban.

Burrows, M.T., Kamenos, N.A., Hughes, D.J., Stahl, H., Howe, J.A., Tett, P. 2014. *Assessment of carbon budgets and potential blue carbon stores in Scotland's coastal and marine environment*. Scottish Natural Heritage Commissioned Report No. 761. Scottish Association for Marine Science, Oban.

Burrows, M.T., Macleod, M., Orr, K. 2010. *Mapping the intertidal seaweed resources of the Outer Hebrides*. Internal Report No. 269. Scottish Association for Marine Science, Oban.

Burrows, M.T., Moore, P., Sugden, H., Fitzsimmons, C., Smeaton, C., Austin, W. *et al*.. 2021. *Assessment of Carbon Capture and Storage in Natural Systems within the English North Sea (Including within Marine Protected Areas)*, A North Sea Wildlife Trusts, Blue Marine Foundation, WWF and RSPB commissioned report.

Burrows, M.T., Tillin, H., Grundy, S., Smeaton, C., Austin, W.E.N., O'Dell, A. 2024a. *The United Kingdom's blue carbon inventory: assessment of marine carbon storage and sequestration potential in the English Channel and Western Approaches Region (including within marine protected areas).* A report to The Wildlife Trusts, WWF and the RSPB. Scottish Association for Marine Science, Oban.

Burrows, M.T., Tillin, H., Grundy, S., Smeaton, C., Austin, W.E.N., O'Dell, A. 2024b. *The United Kingdom's blue carbon inventory: assessment of marine carbon storage and sequestration potential in the Irish Sea and Welsh Coast Region (including within marine protected areas).* A report to The Wildlife Trusts, WWF and the RSPB. Scottish Association for Marine Science, Oban.

Castle, L., Pinder, J., Lillis, H., Manca, E. 2022. *Using an ensemble modelling approach to predict suitable habitat for* Zostera marina *beds,* Modiolus modiolus *beds and* Sabellaria spinulosa *reefs in UK waters*. JNCC Report No. 718. Joint Nature Conservation Committee, Peterborough.

de Haas, H., Boer, W., van Weering, T.C. 1997. Recent sedimentation and organic carbon burial in a shelf sea: the North Sea. *Marine Geology* **144**, 131–146.

den Hartog, C. 1972. The identity of *Zostera marina* var. *angustifolia* Hornemann (Potamogetonaceae). *Blumea: Biodiversity, Evolution and Biogeography of Plants* **20**, 150.

Dennison, W.C., Alberte, R.S. 1986. Photoadaptation and growth of *Zostera marina* L. (eelgrass) transplants along a depth gradient. *Journal of Experimental Marine Biology and Ecology* **98**, 265–282. https://doi.org/10.1016/0022-0981(86)90217-0

Diesing, M., Kröger, S., Parker, R., Jenkins, C., Mason, C., Weston, K., 2017. Predicting the standing stock of organic carbon in surface sediments of the North–West European continental shelf. *Biogeochemistry* **135**, 183–200. https://doi.org/10.1007/s10533-017-0310-4

Diesing, M., Thorsnes, T., Rún Bjarnadóttir, L. 2021. Organic carbon densities and accumulation rates in surface sediments of the North Sea and Skagerrak. *Biogeosciences* **18**, 2139–2160. https://doi.org/10.5194/BG-18-2139-2021

Eakins, B., Sharman, G. 2007. *Volumes of the world's oceans from ETOPO1*. AGU Fall Meeting Abstracts 0999.

Environment Agency. 2022. *The extent and zonation of saltmarsh in England: 2016–2019. An update to the national saltmarsh inventory*. Environment Agency, Bristol.

Epstein, G., Middelburg, J.J., Hawkins, J.P., Norris, C.R., Roberts, C.M. 2022. The impact of mobile demersal fishing on carbon storage in seabed sediments. *Global Change Biology* **28**, 2875–2894. https://doi.org/10.1111/gcb.16105

Flavell, B., Carr, H., Robson, L., Byford, S., Chaniotis, P., Last, E., *et al*. 2020. *Developing the evidence-base to support climate-smart decision making on MPAs*. JNCC Report No. 648. Joint Nature Conservation Committee, Peterborough.

Ford, H., Garbutt, A., Ladd, C., Malarkey, J., Skov, M.W. 2016. Soil stabilization linked to plant diversity and environmental context in coastal wetlands. *Journal of Vegetation Science* **27**, 259–268. https://doi.org/10.1111/jvs.12367

Frankignoulle, M., Canon, C., Gattuso, J.-P. 1994. Marine calcification as a source of carbon dioxide: positive feedback of increasing atmospheric CO_2. *Limnology and Oceanography* **39**, 458–462. https://doi.org/10.4319/lo.1994.39.2.0458

Funck, T., Geissler, W.H., Kimbell, G.S., Gradmann, S., Erlendsson, Ö., McDermott, K. *et al*. 2017. Moho and basement depth in the NE Atlantic Ocean based on seismic refraction data and receiver functions. *Geological Society, London, Special Publications* **447**, 207–231. https://doi.org/10.1144/SP447.1

Furze, M.F.A., Scourse, J.D., Pieńkowski, A.J., Marret, F., Hobbs, W.O., Carter, R.A. *et al*. 2014. Deglacial to postglacial palaeoenvironments of the Celtic Sea: lacustrine conditions versus a continuous marine sequence. *Boreas* **43**, 149–174. https://doi.org/10.1111/bor.12028

Gaffney, V., Finch, S., Thomson, K. 2007. *Mapping Doggerland: The Mesolithic Landscapes of the Southern North Sea*. Archaeopress, Oxford.

Garrard, S.L., Beaumont, N.J. 2014. The effect of ocean acidification on carbon storage and sequestration in seagrass beds; a global and UK context. *Marine Pollution Bulletin* **86**, 138–146. https://doi.org/10.1016/j.marpolbul.2014.07.032

Green, A., Chadwick, M.A., Jones, P.J.S. 2018. Variability of UK seagrass sediment carbon: implications for blue carbon estimates and marine conservation management. *PLoS ONE* **13**, e0204431. https://doi.org/10.1371/journal.pone.0204431

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**, 629962.

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

Hall-Spencer, J., Kelly, J., Maggs, C.A. 2010. *Background document for maerl beds*. OSPAR Commission, London.

Harrison, P.G. 1993. Variations in demography of *Zostera marina* and *Z. noltii* on an intertidal gradient. *Aquatic Botany* **45**, 63–77. https://doi.org/10.1016/0304-3770(93)90053-Y

Haynes, T.A. 2016. *Scottish saltmarsh survey national report*. Scottish Natural Heritage Commissioned Report No. 786. Scottish Natural Heritage, Inverness.

Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C.L., Hughes, K.M., Ellis, N. *et al*. 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *Proceedings of the National Academy of Sciences of the United States of America* **114**, 8301–8306. https://doi.org/10.1073/pnas.1618858114

Hiddink, J.G., van de Velde, S.J., McConnaughey, R.A., De Borger, E., Tiano, J., Kaiser, M.J. *et al*. 2023. Quantifying the carbon benefits of ending bottom trawling. *Nature* **617**, E1–E2. https://doi.org/10.1038/s41586-023-06014-7

Hill, R., Bellgrove, A., Macreadie, P.I., Petrou, K., Beardall, J., Steven, A. *et al*. 2015. Can macroalgae contribute to blue carbon? An Australian perspective. *Limnology and Oceanography* **60**, 1689–1706. https://doi.org/10.1002/lno.10128

Howard, J., Sutton-Grier, A., Herr, D., Kleypas, J., Landis, E., Mcleod, E. *et al*. 2017. Clarifying the role of coastal and marine systems in climate mitigation. *Frontiers in Ecology and the Environment* **15**, 42–50. https://doi.org/10.1002/fee.1451

Howard, J., Sutton-Grier, A.E., Smart, L.S., Lopes, C.C., Hamilton, J., Kleypas, J. *et al*. 2023. Blue carbon pathways for climate mitigation: known, emerging and unlikely. *Marine Policy* **156**, 105788. https://doi.org/10.1016/j.marpol.2023.105788

Ito, Y., Ohi-Toma, T., Nepi, C., Santangelo, A., Stinca, A., Tanaka, N. *et al*. 2017. Towards a better understanding of the *Ruppia maritima* complex (Ruppiaceae): notes on the correct application and typification of the names *R. cirrhosa* and *R. spiralis*. *TAXON* **66**, 167–171. https://doi.org/10.12705/661.11

Jacobs, R.P.W.M. 1979. Distribution and aspects of the production and biomass of eelgrass, *Zostera marina* L., at Roscoff, France. *Aquatic Botany* **7**, 151–172. https://doi.org/10.1016/0304-3770(79)90019-6

Jakobsson-Thor, S., Brakel, J., Toth, G.B., Pavia, H. 2020. Complex interactions of temperature, light and tissue damage on seagrass wasting disease in *Zostera marina*. *Frontiers in Marine Science* **7**, 575183.

Jiménez, C., Xavier Niell, F., Algarra, P. 1987. Photosynthetic adaptation of *Zostera noltii* Hornem. *Aquatic Botany* **29**, 217–226. https://doi.org/10.1016/0304-3770(87)90017-9

Joint Nature Conservation Committee. 2004. *Common Standards Monitoring Guidance for Saltmarsh Habitats*. Joint Nature Conservation Committee, Peterborough.

Joint Nature Conservation Committee. 2018. *European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora* (92/43/EEC). *Conservation status assessment for the habitat: H1330 - Atlantic salt meadows (Glauco-Puccinellietalia maritimae) NORTHERN IRELAND*. Fourth Report by the United Kingdom under Article 17 on the implementation of the Directive from January 2013 to December 2018 No.). Joint Nature Conservation Committee, Peterborough.

Joint Nature Conservation Committee. 2024. *UK Marine Protected Area network statistics*. Available at https://jncc.gov.uk/our-work/uk-marine-protected-area-network-statistics/ (accessed 19 July 2024).

Jones, B.L., Unsworth, R.K.F. 2016. The perilous state of seagrass in the British Isles. *Royal Society of Open Science* **3**, 150596. https://doi.org/10.1098/rsos.150596

Jørgensen, B.B., Bang, M., Blackburn, T.H. 1990. Anaerobic mineralization in marine sediments from the Baltic Sea-North Sea transition. *Marine Ecology Progress Series* **59**, 39–54.

Joshi, S., Farrell, E. 2020. Physical oceanographic drivers of geomorphology of rhodolith/maerl beds in Galway Bay, Ireland. In: *Seafloor Geomorphology as Benthic Habitat*, 2nd edition (Harris, P.T., Baker, E., eds), pp. 231–242. Elsevier, Amsterdam.

Kettle, E., Lawson, H., Carr, H., Chaniotis, P., Byford, S., Woods, H. *et al*. 2020. *Statistics on the extent of blue carbon habitats to support MPA decision-making in Secretary of State waters: results*. Joint Nature Conservation Committee, Peterborough.

Kim, Y.K., Kim, S.H., Lee, K.-S. 2015. Seasonal growth responses of the seagrass *Zostera marina* under severely diminished light conditions. *Estuaries and Coasts* **38**, 558–568. https://doi.org/10.1007/s12237-014-9833-2

Krause-Jensen, D., Duarte, C.M. 2016. Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience* **9**, 737–742. http://dx.doi.org/10.1038/ngeo2790

Krumhansl, K.A., Scheibling, R. 2012. Production and fate of kelp detritus. *Marine Ecology Progress Series* **467**, 281–302. https://doi.org/10.3354/meps09940

La Nafie, Y.A., de los Santos, C.B., Brun, F.G., van Katwijk, M.M., Bouma, T.J. 2012. Waves and high nutrient loads jointly decrease survival and separately affect morphological and biomechanical properties in the seagrass *Zostera noltii*. *Limnology and Oceanography* **57**, 1664–1672. https://doi.org/10.4319/lo.2012.57.6.1664

LaRowe, D.E., Arndt, S., Bradley, J.A., Burwicz, E., Dale, A.W., Amend, J.P. 2020a. Organic carbon and microbial activity in marine sediments on a global scale throughout the Quaternary. *Geochimica et Cosmochimica Acta* **286**, 227–247. https://doi.org/10.1016/j.gca.2020.07.017

LaRowe, D.E., Arndt, S., Bradley, J.A., Estes, E.R., Hoarfrost, A., Lang, S.Q. *et al*. 2020b. The fate of organic carbon in marine sediments – New insights from recent data and analysis. *Earth-Science Reviews* **204**, 103146. https://doi.org/10.1016/j.earscirev.2020.103146

Lewis, P. 2020. *Quantifying intertidal canopy-forming macroalgal production, extent, degradation, and blue carbon potential. PhD thesis.* Aberystwyth University, Aberystwyth.

Loh, P.S., Reeves, A.D., Miller, A.E.J., Harvey, S.M., Overnell, J. 2010. Sediment fluxes and carbon budgets in Loch Creran, western Scotland. *Geological Society, London, Special Publications* **344**, 103–124. https://doi.org/10.1144/SP344.10

Lovelock, C., Reef, R. 2020. Variable impacts of climate change on blue carbon. *One Earth* **3**, 195–211. https://doi.org/10.1016/j.oneear.2020.07.010

Macreadie, P.I., Anton, A., Raven, J.A., Beaumont, N., Connolly, R.M., Friess, D.A. *et al*. 2019. The future of Blue Carbon science. *Nature Communications* **10**, 3998. https://doi.org/10.1038/s41467-019-11693-w

Mao, J., Burdett, H.L., McGill, R.A.R., Newton, J., Gulliver, P., Kamenos, N.A. 2020. Carbon burial over the last four millennia is regulated by both climatic and land use change. *Global Change Biology* **26**, 2496–2504. https://doi.org/10.1111/gcb.15021

Melbourne, L.A., Brodie, J., Rayfield, E.J., Titelboim, D., Lord, O.T., Schmidt, D.N. 2023. Environmental impacts on the structural integrity of British rhodoliths. *Scientific Reports* **13**, 13473. https://doi.org/10.1038/s41598-023-40292-5

Melbourne, L.A., Hernández-Kantún, J.J., Russell, S., Brodie, J. 2017. There is more to maerl than meets the eye: DNA barcoding reveals a new species in Britain, *Lithothamnion erinaceum* sp. nov. (Hapalidiales, Rhodophyta). *European Journal of Phycology* **52**, 166–178. https://doi.org/10.1080/09670262.2016.1269953

Miller, L.C., Smeaton, C., Yang, H., Austin, W.E.N. 2023. Carbon accumulation and storage across contrasting saltmarshes of Scotland. *Estuarine, Coastal and Shelf Science* **282**, 108223. https://doi.org/10.1016/j.ecss.2023.108223

O'Dell, A.R. 2022. *Scotland's blue carbon: the contribution from seaweed detritus*. PhD thesis, University of the Highlands and Islands and Scottish Association for Marine Science, Oban.

Overnell, J., Young, S. 1995. Sedimentation and carbon flux in a Scottish sea loch, Loch Linnhe. *Estuarine, Coastal and Shelf Science* **41**, 361–376.

Parker, R., Benson, L., Graves, C., Kröger, S., Viera, R. 2021. *Blue carbon stocks and accumulation analysis for Secretary of Stata (SoS) region*. Cefas Project Report for Defra. Cefas, Lowestoft.

Peralta, G., Brun, F.G., Hernández, I., Vergara, J.J., Pérez-Lloréns, J.L. 2005. Morphometric variations as acclimation mechanisms in *Zostera noltii* beds. *Estuarine, Coastal and Shelf Science* **64**, 347–356. https://doi.org/10.1016/j.ecss.2005.02.027

Pessarrodona, A., Moore, P.J., Sayer, M.D.J., Smale, D.A. 2018. Carbon assimilation and transfer through kelp forests in the NE Atlantic is diminished under a warmer ocean climate. *Global Change Biology* **24**, 4386–4398. https://doi.org/10.1111/gcb.14303

Potouroglou, M. 2017. *Assessing the role of intertidal seagrasses as coastal carbon sinks in Scotland*. PhD thesis, Edinburgh Napier University, Edinburgh.

Potouroglou, M., Bull, J.C., Krauss, K.W., Kennedy, H.A., Fusi, M., Daffonchio, D. *et al*. 2017. Measuring the role of seagrasses in regulating sediment surface elevation. *Scientific Reports* **7**, 11917. https://doi.org/10.1038/s41598-017-12354-y

Provan, J., Wilson, S., Portig, A.A., Maggs, C.A. 2008. The importance of reproductive strategies in population genetic approaches to conservation: an example from the marine angiosperm genus *Zostera*. *Conservation Genetics* **9**, 271–280. https://doi.org/10.1007/s10592-007-9338-7

Raven, J. 2018. Blue carbon: past, present and future, with emphasis on macroalgae. *Biology Letters* **14**, 20180336. https://doi.org/10.1098/rsbl.2018.0336

Sala, E., Mayorga, J., Bradley, D., Cabral, R.B., Atwood, T.B., Auber, A. *et al*. 2021. Protecting the global ocean for biodiversity, food and climate. *Nature* **592**, 397–402. https://doi.org/10.1038/s41586-021-03371-z

Scourse, J., Saher, M., Van Landeghem, K.J.J., Lockhart, E., Purcell, C., Callard, L. *et al*. 2019. Advance and retreat of the marine-terminating Irish Sea Ice Stream into the Celtic Sea during the Last Glacial: timing and maximum extent. *Marine Geology* **412**, 53–68. https://doi.org/10.1016/j.margeo.2019.03.003

Smale, D.A., Burrows, M.T., Evans, A.J., King, N., Sayer, M.D.J., Yunnie, A.L.E., Moore, P.J., 2016. Linking environmental variables with regional-scale variability in ecological structure and standing stock of carbon within UK kelp forests. *Mar Ecol Prog Ser* **542**, 79–95. https://doi.org/10.3354/meps11544

Smale, D.A., Pessarrodona, A., King, N., Burrows, M.T., Yunnie, A., Vance, T. *et al*. 2020. Environmental factors influencing primary productivity of the forest-forming kelp *Laminaria hyperborea* in the northeast Atlantic. *Scientific Reports* **10**, 12161. https://doi.org/10.1038/s41598-020-69238-x

Smeaton, C., Austin, W.E.N., Davies, A.L., Baltzer, A., Howe, J.A., Baxter, J.M. 2017. Scotland's forgotten carbon: a national assessment of mid-latitude fjord sedimentary carbon stocks. *Biogeosciences* **14**, 5663–5674. https://doi.org/10.5194/bg-14-5663-2017

Smeaton, C., Burden, A., Ruranska, P., Ladd, C.J.T., Garbutt, A., Jones, L. *et al*. 2022. Using citizen science to estimate surficial soil Blue Carbon stocks in Great British saltmarshes. *Frontiers in Marine Science* **9**, 959459.

Smeaton, C., Hunt, C.A., Turrell, W.R., Austin, W.E.N. 2021a. Marine sedimentary carbon stocks of the United Kingdom's Exclusive Economic Zone. *Frontiers in Earth Science* **9**, 593324. https://doi.org/10.3389/feart.2021.593324

Smeaton, C., Ladd, C., Miller, L., McMahon, L., Garrett, E., Barlow, N.L.M. *et al*. 2023. Organic carbon stocks of Great British Saltmarshes. *Frontiers in Marine Science* **10**, 1229486. https://doi.org/10.3389/fmars.2023.1229486

Smeaton, C., Miller, L.C., Ruranska, P., Austin, W.E.N. 2021b. *Organic carbon density of surficial soils across Scottish saltmarshes*. Marine Scotland, Edinburgh. https://doi.org/10.7489/12389-1

Smeaton, C., Yang, H., Austin, W.E.N. 2021c. Carbon burial in the mid-latitude fjords of Scotland. *Marine Geology* **441**, 106618. https://doi.org/10.1016/j.margeo.2021.106618

Smetacek, V., Zingone, A. 2013. Green and golden seaweed tides on the rise. *Nature* **504**, 84–88. https://doi.org/10.1038/nature12860

Smith, R.W., Bianchi, T.S., Allison, M., Savage, C., Galy, V. 2015. High rates of organic carbon burial in fjord sediments globally. *Nature Geoscience* **8**, 450–453. https://doi.org/10.1038/NGEO2421

Stoker, M.S., Harland, R., Graham, D.K. 1991. Glacially influenced basin plain sedimentation in the southern Faeroe-Shetland Channel, northwest United Kingdom continental margin. *Marine Geology* **100**, 185–199. https://doi.org/10.1016/0025-3227(91)90232-S

St-Onge, G., Hillaire-Marcel, C. 2001. Isotopic constraints of sedimentary inputs and organic carbon burial rates in the Saguenay Fjord, Quebec. *Marine Geology* **176**, 1–22. https://doi.org/10.1016/S0025-3227(01)00150-5

Straume, E. O., Gaina, C., Medvedev, S., Hochmuth, K., Gohl, K., Whittaker, J.M. *et al*. 2019. GlobSed: Updated total sediment thickness in the world's oceans. *Geochemistry, Geophysics, Geosystems* **20**, 1756–1772. https://doi.org/10.1029/2018GC008115

Strong, J.A., Mazik, K., Piechaud, N., Bryant, L., Wardell, C., Hull, S. *et al*. 2021. *Blue carbon restoration in Northern Ireland – feasibility study*. Ulster Wildlife, Belfast.

Trisos, C.H., Merow, C., Pigot, A.L. 2020. The projected timing of abrupt ecological disruption from climate change. *Nature* **580**, 496–501. https://doi.org/10.1038/s41586-020-2189-9

Turrell, W.R., Austin, W.E.N., Philbrick, S.P., Tilbrook, C., Kennedy, H. 2023. Clarifying the role of inorganic carbon in blue carbon policy and practice. *Marine Policy* **157**, 105873. https://doi.org/10.1016/j.marpol.2023.105873

Vandendriessche, S., Vincx, M., Degraer, S. 2007. Floating seaweed and the influences of temperature, grazing and clump size on raft longevity – A microcosm study. *Journal of Experimental Marine Biology and Ecology* **343**, 64–73. https://doi.org/10.1016/j.jembe.2006.11.010

Wadham, J., Death, R., Monteiro, F., Tranter, M., Ridgwell, A., Raiswell, R. *et al*. 2013. The potential role of the Antarctic Ice Sheet in global biogeochemical cycles. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* **104**, 55–67. https://doi.org/10.1017/S1755691013000108

Walker, F.T. 1954. Distribution of Laminariaceae around Scotland. *Nature* **173**, 766–768. https://doi.org/10.1038/173766b0

Wheater, E., Woods, H., Castle, L. 2020. *Statistics on the extent of blue carbon habitats to support MPA decision-making in Secretary of State waters: methodology*. Joint Nature Conservation Committee, Peterborough.

Wilson, K.L., Lotze, H.K. 2019. Climate change projections reveal range shifts of eelgrass *Zostera marina* in the Northwest Atlantic. *Marine Ecology Progress Series* **620**, 47–62. https://doi.org/10.3354/meps12973

Woods, M.A., Wilkinson, I.P., Leng, M.J., Riding, J.B., Vane, C.H., Lopes dos Santos, R.A. *et al*. 2019. Tracking Holocene palaeostratification and productivity changes in the Western Irish Sea: a multi-proxy record. *Palaeogeography, Palaeoclimatology, Palaeoecology* **532**, 109231. https://doi.org/10.1016/j.palaeo.2019.06.004

Yesson, C., Bush, L.E., Davies, A.J., Maggs, C.A., Brodie, J. 2015. The distribution and environmental requirements of large brown seaweeds in the British Isles. *Journal of the*

Marine Biological Association of the United Kingdom **95**, 669–680. https://doi.org/10.1017/S0025315414001453

7 GLOSSARY

influx	The rate of arrival of carbon to long-term stores, usually as particulate organic carbon (POC) to seabed sediments or saltmarsh soils, from the combined available sources of POC (such as phytoplankton, macroalgae, saltmarsh plants etc.).
long-term carbon stores	Carbon that is locked away from atmospheric circulation for significant time periods (generally over 100 years).
organic carbon (OC)	Compounds of carbon, nitrogen and hydrogen and, in some cases, oxygen and sulphur, used by living organisms in the structure of their cells and as a source of energy.
outflux	The rate of production of carbon for long-term storage, usually particulate organic carbon (POC) either exported to other habitats, such as from kelp or phytoplankton to seabed sediments, or stored locally, such as from saltmarsh vegetation to saltmarsh soils.
particulate organic carbon (POC)	Organic carbon that is in the form of solid particles, derived from dead plant material.
rock	An extensive geological term, but limited in hydrography to hard, solid masses on the Earth's surface that rise from the bottom of the sea. Rock may be either completely submerged or project permanently, or at times, above water.
sand	Medium-grained sediment with a diameter range of 0.063–2 mm. This is the most common sediment on the continental shelf.
sea loch (fjord)	A former glacial valley, with steep walls and a U-shaped profile, now occupied by the sea.
sediment accumulation rate (SAR)	The rate at which sediment builds up on the seabed, expressed in cm/yr.
sedimentation	The process of deposition of mineral grains or precipitates in beds or other accumulations.
sequestration	The process of addition of solid carbon to the carbon store.
short-term carbon stores	Carbon that is temporarily fixed or removed from atmospheric circulation for less significant time periods (e.g., in living biomass). 'Store' as a verb refers to carbon added to either short-term or long-term stores.

Annex 1. Sources for Habitat Data

Table A1. Sources for habitat data

Title	Data source	Data sub-source	Data owner	Restrictions	Permissions request needed?
Seastar DORIS (DORset Integrated Seabed survey)	Dorset Wildlife Trust: Peter Tinsley PTinsley@dorsetwildlifetrust.org.uk	n/a	Dorset Wildlife Trust	Creative Commons by Attribution (CC-BY). Permission received from Peter Tinsley <PTinsley@dorsetwildlifetrust.org.uk>	No
Saltmarsh Extent & Zonation	www.data.gov.uk	Environment Agency	Environment Agency	Open Government License http://www.data.gov.uk/dataset/0e9982d3-1fef-47de-9af0-4b1398330d88/saltmarsh-extent-zonation	No
Saltmarsh Extents Natural Resources Wales	https://datamap.gov.wales/layers/inspire-nrw:NRW_SALTMARSH_EXTENTS	DataMapWales	Welsh Government	Open Government License www.nationalarchives.gov.uk/doc/open-government-licence/version/3/	No
EUSeaMap	www.emodnet-seabedhabitats.eu/about/euseamap-broad-scale-maps/	EMODnet	European Marine Observation and Data Network (EMODnet) Seabed Habitats initiative (www.emodnet-seabedhabitats.eu), funded by the European Commission	Credit: Licensed under CC-BY 4.0 from the European Marine Observation and Data Network (EMODnet) Seabed Habitats initiative (www.emodnet-seabedhabitats.eu), funded by the European Commission	No

Title	Data source	Data sub-source	Data owner	Restrictions	Permissions request needed?
C20220127_AnnexI_ Reefs_v8_3_OpenData	https://hub.jncc.gov.uk/assets/8f886e47-31d6-477e-9240-65ac42bee709		Joint Nature Conservation Committee (JNCC)	No limitations on public access. Use constraints: Available under the Open Government Licence v3. Attribution statement 'Contains JNCC data © copyright and database right 2021'	No
Natural England Marine Habitats	www.data.gov.uk/dataset/bfc23a6d-8879-4072-95ed-125b091f908a/marine-habitats-and-species-open-data	Defra	Natural England	These datasets are available under the Open Government Licence (OGL).	No