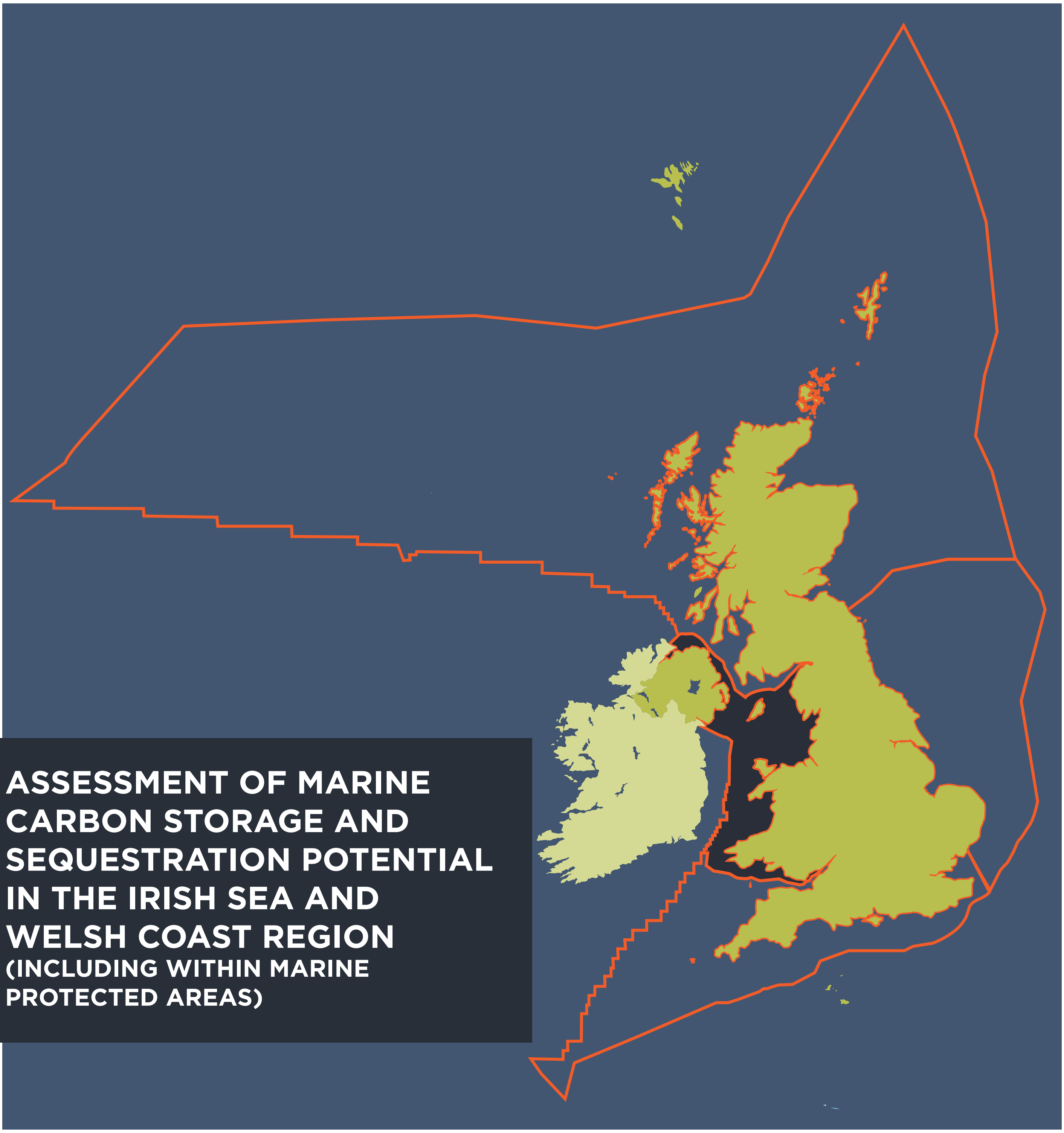
THE UNITED KINGDOM'S BLUE CARBON INVENTORY:



ASSESSMENT OF MARINE CARBON STORAGE AND SEQUESTRATION POTENTIAL IN THE IRISH SEA AND WELSH COAST REGION

(INCLUDING WITHIN MARINE PROTECTED AREAS)

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)

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Assessment of Marine Carbon Storage and Sequestration Potential in the Irish Sea and Welsh Coast Region (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 known as the Irish Sea and Welsh Coast Region, which has coastlines in Wales, Northern Ireland and parts of the English coast ending at the Solway Firth. This report forms part of the UK's Blue Carbon Inventory alongside regional reports that focus on the English North Sea (Burrows *et al.,* 2021), the English Channel and Western Approaches Region (Burrows *et al.,* 2024a) and Scotland(Burrows *et al.,* 2024b). As in the other reports, the main objective was to assess the present extent and distribution of habitats, with emphasis on those that are identified as blue carbon habitats. Further aims were to evaluate the blue carbon potential of the Region by (1) estimating the quantity of carbon currently stored within blue carbon habitats, (2) establishing the average net sequestration rate (in g C m^2/yr), (3) estimating the potential net total sequestration (in g C/yr) for each blue carbon habitat, (4) estimating the carbon stored and potential sequestration in Irish Sea and Welsh Coast Region marine protected areas (MPAs), and (5) further developing methods and approaches to this analysis that can be refined for future studies. 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 ecosystems, their associated sediment stores, and the top 10 cm of sublittoral seabed sediment stores. The results are intended to inform management decisions and identify opportunities to protect blue carbon ecosystems, the habitats they provide and their carbon sequestration potential. Evidence of this nature will contribute to exploration of the potential of the UK's marine protected area (MPA) network to help mitigate against the effects of climate change.

The extents of blue carbon habitats for the Irish Sea and Welsh Coast Region were derived from available open 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 long-term stores in surface sediments (Smeaton *et al*., 2021).

Main Findings

• The Irish Sea and Welsh Coast Region covers an area of **43,112 km²**.

• This analysis considers the biomass, soil carbon content and annual sequestration capacity of blue carbon ecosystems in the Irish Sea and Welsh Coast Region. Sizes of long-term stores of carbon are provided only for the top 10 cm of the seabed, known as the bioturbated Holocene sediment layer, since this is the layer of the sediment that receives additions to the total store. Carbon store sizes given here therefore represent only a fraction of the overall carbon stored in the full thickness of the seabed sediments.

• **Carbon in long-term stores** is carbon that is locked away from atmospheric circulation for significant time periods (generally over 100 years). In total, **15.7 million tonnes (Mt) of OC in long-term stores** are found in the Region, with 93.7% of that total stored in the top 10 cm of seabed sediments. The remaining 6.3% (**1.0 Mt**) of OC is found **within coastal vegetated blue carbon habitats**, predominantly stored in the soils of coastal saltmarshes (94%) and in sediment in seagrass beds (6%). Seabed sediments are thus by far the most important habitat for carbon storage in the Irish Sea and Welsh Coast Region. Although coastal blue carbon habitats (kelp beds, intertidal macroalgae, saltmarshes and seagrass beds) represent only 5% of the total area of the Region, they contain 13% of the total OC stores, largely due to the extensive saltmarshes in the Region, and they account for 18% of annual accumulated OC in those stores. Annually, an estimated **1.3 Mt of OC is added to sediment stores** across the Region, predominantly within mud and sand/mud seabed sediments. Coastal **blue carbon habitats** (saltmarshes and seagrass beds) **store** a considerably smaller fraction of this (**123,000 t C/yr**; 10% of the total annual value, albeit at a higher rate per unit area), with saltmarsh biomass and soils accounting for the vast majority (98%) of the accumulation among coastal blue carbon habitat stores.

• **Carbon in short-term stores** is that which is temporarily fixed or removed from atmospheric circulation for less significant time periods. Kelp beds (**204,000 t C**) and intertidal macroalgae (**8,800 t C**) contain OC as living biomass.

• In this Region the marine protected areas (MPAs) – that is, Marine Conservation Zones (MCZs), Marine Nature Reserves (MNRs), Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Areas of Special Scientific Interest (ASSIs) and Sites of Special Scientific Interest (SSSIs) – cover a total of **31,177 km^2**, representing 72% of the area of the Irish Sea and Welsh Coast Region, albeit not accounting for multiple designations of some areas. Long-term stores of carbon within the protected areas are estimated to hold **10.4 Mt of OC**, accounting for 70% of the total OC stores in the Region, and **7.6 Mt of IC**, accounting for 49% of the total IC stored across the Region. These values do reflect the multiple designations of some areas as MPAs and will be lower if that double counting is considered. Combining the areas covered and counting the overlapping areas only once (Burrows *et al.*, 2024c) gives a total area of 20,507 km^2 covered by the MPAs in the Irish Sea and Welsh Coast Region, such that the total area covered by any kind of protected area is 43% of the area of the Region.

• Among MPAs, sublittoral MCZs and SACs contain the largest long-term stores of OC and IC (6.4 Mt C), but inshore, littoral MPAs, and notably the smaller marine portions of SSSIs, have the highest densities (0.49 C kg/m^2 for SSSIs) and rates of OC accumulation per unit area (45.5 g C kg/m^2/yr for SSSIs) in their coastal muds, saltmarshes and seagrass beds. Marine protected areas with predominantly rocky habitats have less OC in long-term stores and lower OC accumulation rates but do support extensive kelp beds that contribute carbon to neighbouring areas of sediment.

• For policy considerations, a distinction may be made between 'actionable' blue carbon ecosystems, for which management interventions can be applied and for which carbon markets may be developed (such as the UK Saltmarsh Code[1]), and 'emerging' blue carbon ecosystems (kelp, intertidal macroalgae and the significant amounts of carbon in long-term stores within marine sediments), where a precautionary approach to management is needed while uncertainties around carbon fixation and management issues may have to be addressed.

• Growth and reproduction of algae (including micro- and macroalgae) and plants, with subsequent breakdown and transport to stores in the seabed, are the primary mechanism for removal of CO_2 by the marine ecosystem in the Region. Unlike rates of plant growth, the proportion of plant and algal detritus that reaches carbon long-term stores has been little studied. Reflecting values typically adopted in ecosystem models, a value of 10% was used as the percentage of newly fixed plant OC that was transported from biomass and stored in seabed sediments. Based on this assumption, **0.4 Mt C/yr** is estimated to be added to the particulate organic carbon (POC) pool for transport and incorporation into stores. Production of POC exported to long-term sediment stores in the Region is dominated by **phytoplankton** (**351,000 t C/yr**), with much smaller fractions contributed by **kelp** (**49,000 t C/yr**), **saltmarshes** (**2,900 t C**), **seagrass beds** (**700 t C/yr**) and **intertidal macroalgae** (**2,500 t C/yr**). Biogenic reefs are extensive in the Region, particularly the subtidal tubeworm *Sabellaria spinulosa*.

[1] www.ceh.ac.uk/our-science/projects/uk-saltmarsh-code

These areas are similar to surrounding sediments in their ability to store carbon, which they do by trapping particulate material in the reefs; such positive contributions to OC storage may be offset by CO_2 released during calcification of reef-building material.

• 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.

• Integrating the understanding of carbon capture and storage by marine habitats into decisions relating to marine management could 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 long-term carbon stores should 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 activities. The predominant anthropogenic source of physical disturbance in the Irish Sea and Welsh Coast Region is demersal fishing, which occurs throughout the Region, but deployment of moorings and installation of offshore energy platforms and associated cables and pipelines also disturb the seabed. However, for subtidal sediments that are also subject to natural background disturbance the net effects are highly uncertain, with some authors suggesting greater susceptibility of OC sediment stores (Sala *et al.*, 2021), and others emphasising the relative stability of the material stored in sediments (Hiddink *et al.*, 2023).

• The impacts of increased atmospheric CO_2 concentrations, such as climate change and ocean acidification, 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 potential benefit for photosynthetic species (e.g., kelp and other macroalgae).

• The main evidence gaps identified by this report were uncertainty about the transport of POC from source to eventual sink, lack of accurate estimates of total sediment volume and its carbon content (i.e., below the top 10 cm reported), and the need to calculate CO_2 remineralisation from seabed disturbance.

Table of Contents

Acronyms and Abbreviations

ASSI	Area of Special Scientific Interest
BAP	Biodiversity Action Plan
BGS	British Geological Survey
Cefas	Centre for Environment, Fisheries and Aquaculture Science
DAERA	Department of Agriculture, Environment and Rural Affairs
DEFA	Department of Environment, Food and Agriculture (Isle of Man)
Defra	Department of Environment, Food and Rural Affairs
DOI	Department of Infrastructure (Isle of Man)
DOM	Dissolved organic matter
EEZ	Exclusive Economic Zone
EMODnet	European Marine Observation and Data Network
EUNIS	European Nature Information System
GIS	Geographic information system
IC	Inorganic carbon
ICES	International Council for the Exploration of the Sea
JNCC	Joint Nature Conservation Committee
MCZ	Marine Conservation Zone
MDS	Multidimensional scaling
MEDIN	Marine Environmental Data and Information Network
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
NM	Nautical mile
NNR	National Nature Reserve

NOC	National Oceanography Centre
NRW	Natural Resources Wales
OC	Organic carbon
POC	Particulate organic carbon
POM	Particulate organic matter
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
WFD	Water Framework Directive (European Union)
WISMB	Western Irish Sea Mud Belt
WWF	World Wildlife Fund

1 Introduction to the UK Blue Carbon Assessment

1.1 Background and rationale

This series of reports, commissioned by WWF, The Wildlife Trusts and the RSPB, takes a habitat-orientated approach to assess marine carbon stores inUK seas, including such stores within marine protected areas (MPAs). 'Blue carbon' ecosystems are broadly considered here to be all those ecosystems that make significant contributions to the fixation 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 fix and store (i.e., sequester) 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 short-term and long-term stores and of rates of carbon fluxes. The report considers exports from and imports to these habitats, and threats to short- and long-term stores and fluxes, as well as the potential for restoring lost habitats to improve carbon storage and sequestration in the future. 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 average sequestration capacity of each habitat.

This project has been carried out in distinct phases and divided into four regions, namely 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 (this report) and Scotland (Burrows *et al.*, 2024b). These reports are combined and synthesised into a UK-scale assessment (Burrows *et al.*, 2024c). The resulting synthesis and assessment of carbon sequestration capacity aims to establish a baseline that will help to guide conservation and restoration efforts.

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 zone. The approach follows that of successful and widely used audits of carbon storage and sequestration processes, primarily the review of Scotland's blue carbon stores (Burrows *et al.*, 2014) and more recently the reports of the assessment of carbon capture and storage in the English North Sea Region (Burrows *et al.*, 2021), the English Channel and Western Approaches Region (Burrows *et al.,* 2024a) and Scotland (Burrows *et al.,* 2024b) that accompany this report. Within the aforementioned projects, further partitioning of blue carbon stores and processes among MPAs informed the role of designated areas in protecting the capacity of coastal and offshore habitats to sequester carbon (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.*, 2020) 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 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.*, 2019; Kettle *et al.*, 2020; Wheater *et al.*, 2020) and carbon types stored (Diesing *et al.*, 2017; Smeaton *et al.*, 2021), based on relationships between known records and data layers for physical and biological drivers of species distributions and 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 natural processes such as wave-driven sediment resuspension and river-derived freshwater 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 (in 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 MPAs, including Marine Conservation Zones (MCZs) in England, Wales and Northern Ireland, Marine Nature Reserves (MNRs) in the Isle of Man Territorial Seas, Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) in all devolved administrations, and Sites of Special Scientific Interest (SSSIs) with areas below the highest astronomical tide mark in all devolved administrations, as well as Areas of Special Scientific Interest (ASSIs) in Northern Ireland (see Figure 1), are evaluated and combined with existing work on the contribution of habitats within MCZs (Flavell *et al.*, 2020). This regional report is the third in a series of four, and gives a breakdown of carbon stores and sequestration capacity within MPAs, ASSIs and SSSIs (all listed in Table 14) in the Irish Sea and Welsh Coast Region.

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 sinks in the UK (saltmarsh, kelp forests, 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, using the top 10 cm of sediment for comparisons
- 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 carbon sequestration rates of MPAs in the UK and Isle of Man (NCMPAs, MCZs, MNRs, SACs, SPAs, SSSIs and ASSIs)
- to further develop analytical methodology and approaches that can be refined on an ongoing basis.

The results are intended to help to inform management decisions and identify opportunities to enhance the biodiversity and carbon sequestration potential of the seabed. 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 storing carbon.

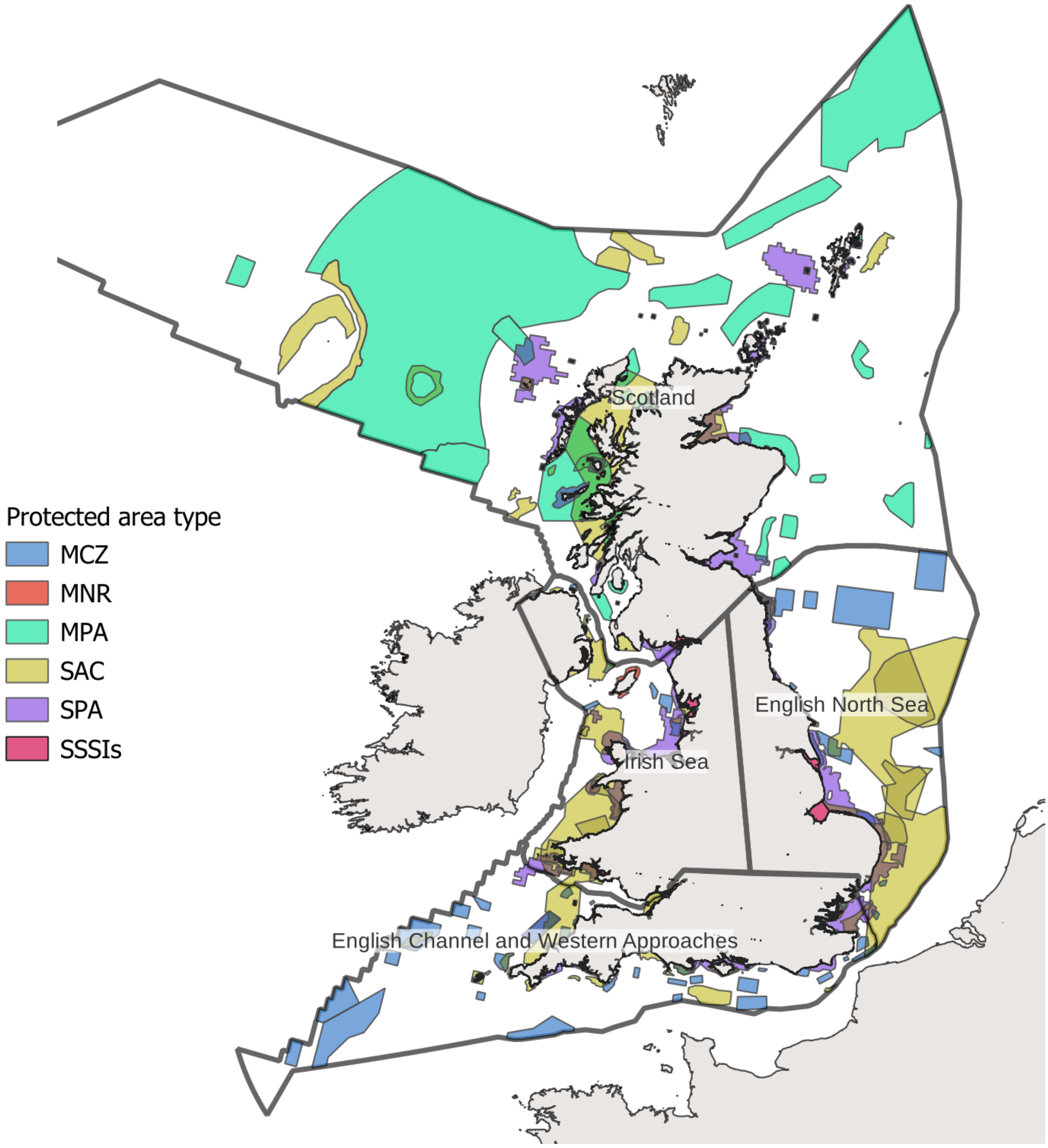


Figure 1. The UK's marine protected areas, showing the four UK Blue Carbon Inventory regions. Protected area types include Marine Conservation Zones (MCZs) in England and Wales, Marine Protected Areas (MPAs) in Scotland, Marine Nature Reserves (MNRs) in the Isle of Man Territorial Seas, and Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) in all devolved administrations. Sites of Special Scientific Interest (SSSIs) and Areas of Special Scientific Interest (ASSIs) are not shown, but are predominantly coastal.

1.3 GIS methods

Standardised methods, outlined in this section, were used for each of the regional reports that make up this series, adopting and developing the methods 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 Irish Sea and Welsh Coast Region (see Section 2), biotope map data were downloaded, inspected and assessed. Sources of habitat information that were used are listed in Annex 1. Biotope and EUNIS codes for polygons were assigned to blue carbon habitats. Data sources used for deriving estimates for habitat extents in the Region included the UK Government Marine Habitats dataset (published by Natural England), Welsh Government datasets (published by Natural Resources Wales), the Northern Ireland Open Data NI portal, and EUNIS seabed maps (EUSeaMap 2019) (see Annex 1). These datasets cover most of the seabed in the Irish Sea and Welsh Coast Region. Included are high-resolution polygon data at scales that allow the intersection of habitats with MPA outlines to determine the extent of habitats within each MPA. Presenting the available data in this way exposes potential discrepancies or gaps in certain regions. For example, it can be noted that the Natural England seabed habitat data for the Irish Sea and Welsh Coast Region has large gaps along the coasts of Wales and Cumbria when compared with the EU habitat dataset. The EU habitat dataset does miss some areas of the coast which are particularly pertinent to the present report (see Figure 2).

Shapefile data for known habitat extents were also downloaded from the relevant national online portals (mentioned earlier) to give accurate values. These habitats included saltmarshes and seagrass. This analysis permits scaling up of habitat-specific carbon stores and sequestration rates to whole MPAs and the entire Irish Sea and Welsh Coast Region itself. Total extents for the main habitat types for the Region are presented.

It can also be useful to compare existing known extents of certain habitats or species with point-source data. These data can be readily accessed from the archive for marine species and habitats (an open source provided by the Marine Biological Association and supported by Defra, the Scottish Government and MEDIN, available at DASSH.ac.uk). Point-source data are useful when determining the accuracy of shapefile data, but the full extents of habitats are derived from existing shapefiles or from existing models (e.g., kelp extents). Where point-source data are shown, this is clearly specified.

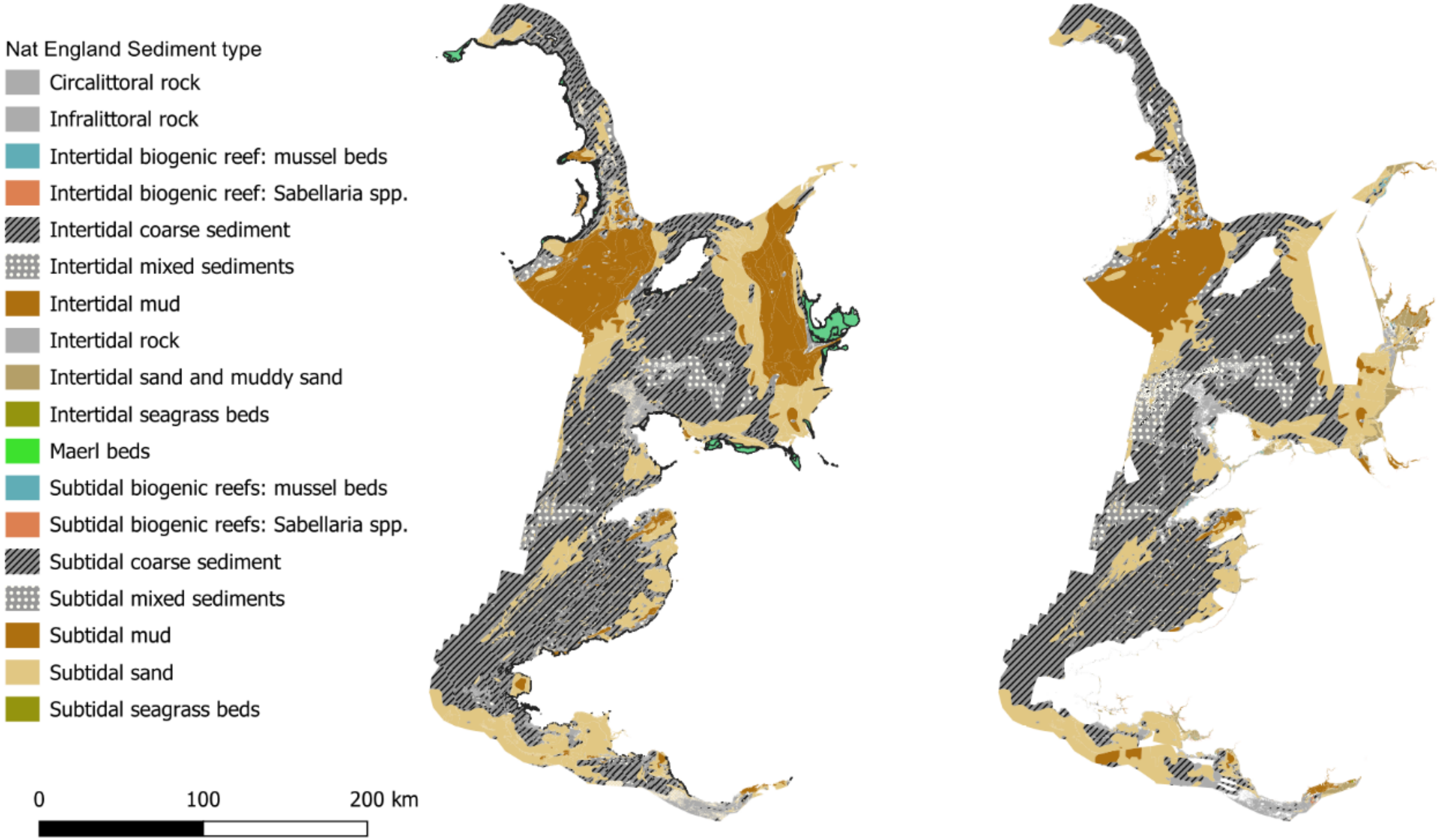


Figure 2. Extents of seabed habitat data for the Irish Sea and Welsh Coast Region from (left) EUSeaMap 2019 and (right) Natural England Marine Habitats and Species Open Data. Note the gaps in coverage by the Natural England dataset in coastal areas of Wales and Cumbria.

After merging with the habitat datasets, the marine protected area shapefiles (MPAs, MCZs, MNRs, SACs, SPAs, ASSIs and SSSIs clipped to each Region to address any marine protected areas overlapping between Regions) were separated into polygons. Marine protected area shapefiles were used to clip sections of the merged layer of section overlap and then exported for area calculations for habitat categories. Extents (in km^2) were estimated for every marine protected area by summing the areas of their component polygons in GIS, and after reading shapefiles using the R statistical package.

1.3.2 Carbon stores in MPAs

Carbon stores for the entire Region and for individual MPAs were estimated from existing spatial data. Organic and inorganic carbon densities as gridded (raster) data were interpolated from British Geological Survey (BGS) samples onto 300-m grid maps taken from Smeaton *et al*. (2021) (supplementary material), downloaded from the links specified within the paper. Carbon density maps (see Figure 10 and Figure 11) covered most of the UK's Exclusive Economic Zone (EEZ), and were cropped to the Irish Sea and Welsh Coast Region. Values were extracted for each MPA from these gridded datasets by re-projecting MPA shapefiles to the same coordinate system as the carbon density maps (ETRS89) and selecting those grid cells that lay inside the MPA polygons using the 'extract' function of *raster* library in R (see Hijmans, 2022). Total carbon (OC and IC) for each Region and for each MPA was calculated as the product of average carbon density per unit area (in g $C/m^2/yr$) and the total area of the Region or MPA.

1.3.3 Carbon accumulation from habitat-specific assimilation rates in MPAs

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. To estimate the area-specific rates and total carbon accumulation for each of the MPAs, the Natural England Marine Habitats and Species data layer (see Annex 1) was first cropped to the Irish Sea and Welsh Coast Region, and the intersection between this layer and the MPA layer was calculated in GIS (QGIS 3.2.0). That process allowed the area of each habitat type (based on its EUNIS 2012 Level 3 classification code) per MPA to be calculated. The sum of the products of component habitat areas and habitat-specific process rates (for OC accumulation) gave the total accumulation of OC for that MPA, and the average rate of accumulation when divided by the area of the MPA (see Section 3.2.4).

2 Blue Carbon Ecosystems of the Irish Sea and Welsh Coast Region

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 6) provides definitions of the technical terms used here.

2.1 Environmental setting of the Irish Sea and Welsh Coast Region

In this section, blue carbon habitats are described and reviewed in terms of their carbon production, sequestration and storage capacities, first across all regions of the UK and then in the context of the Irish Sea and Welsh Coast Region. Process rate estimates are based on the existing literature and available data. Data specific to the Irish Sea and Welsh Coast Region are presented following a general review of the relevant ecology and status of each habitat in the UK. Where relevant, recent reports that have estimated carbon storage, sequestration and standing stores for UK coastal and marine habitats (Burrows *et al*., 2014, 2017, 2021; Armstrong *et al*., 2020; Gregg *et al*., 2021) (see Table 9) are used as primary sources.

2.1.1 Countries and coastlines included in this report

The Irish Sea in the North Atlantic separates Ireland from Great Britain. In the northern part of the Irish Sea the North Channel borders with Northern Ireland and Scottish marine territorial boundaries; the southern part of Wales and Ireland connects to the Atlantic at St George's Channel. The region discussed in this report includes the Northern Irish coast, the entire Welsh coast, part of the English coast (from a small region of the Cheshire coast to the Cumbrian coast up to the border of Scotland) and the self-governed Isle of Man Territorial Seas coastline. The waters and coastline within the Republic of Ireland's territory are not included in this report.

2.1.2 The Welsh coastline

The Welsh coastline is approximately 2,700 km long, and is the longest coastline in the Irish Sea and Welsh Coast Region covered in this report. The most southern part of the Welsh coastline is within the Bristol Channel, which is divided between the Irish Sea and Welsh Coast Region and the English Channel and Western Approaches Region (Burrows *et al.,* 2024a).

2.1.3 The Northern Ireland marine area

The inshore region of the Northern Ireland marine area extends out from the mean high-water spring-tide mark for 12 nautical miles (NM), and incorporates rivers and sea loughs. The area also includes an offshore region, which extends in a south-eastwardly direction from the 12 NM limit to the outer boundary of the Northern Ireland marine zone. The furthest point of this zone is 31 NM from land.

2.1.4 The Isle of Man

The self-governing Isle of Man has Territorial Seas that extend to 12 NM from its coastline. The marine boundary of the territorial waters surrounding the Isle of Man shares its borders with the territorial waters of Wales to the south, Scotland to the north, Northern Ireland to the west and England to the east.

2.1.5 England

In the north-east part of the Irish Sea and Welsh Coast Region is the north-western coast of England, which is separated from Scotland in the north by the Solway Firth, and from Wales in the south by the Dee Estuary. The coastlines of Lancashire, Cumbria and Cheshire are included in this report.

2.2 Habitat extent and distribution

Natural England Marine Habitats and Species Open Data and the EUSeaMap 2019 (see Annex 1) were the primary source of high-resolution polygon data at scales that allow the intersection of habitats with MPA outlines to determine the extent of habitats within each MPA. This analysis permits scaling up of habitat-specific carbon stores and sequestration rates to whole MPAs and the entire Irish Sea and Welsh Coast Region itself. Total extents of the main habitat types for the Irish Sea and Welsh Coast Region are shown in Table 1.

Table 1. Extents of seabed habitats (in km^2 and as percentage area) in the Irish Sea and Welsh Coast Region derived for littoral habitats from Natural England Marine Habitats and Species Open Data and for sublittoral habitats from EUSeaMap 2019. Drawing upon the two datasets allows a full picture of the seabed region to be built. Values along the bottom of the table are the percentages of the total area of the Region covered by each type of MPA. Extent values refer to areas where seabed habitats have been mapped. Unmapped areas for habitats account for differences between totals for different types of designations given here and those given elsewhere (see Table 14).

		Area (km^2)						Percent area			
EUNIS name		Region	MCZ	SAC	SPA	SSSI	MNR	MCZ	SAC	SSSI	MNR
Littoral habitats - Physical											
Littoral rock and other hard substrata	A1	72.8	5.3	45.9	25.0	31.3	0.5	7%	63%	43%	1%
Infralittoral rock and other hard substrata	A3	103.8	6.7	104.6	40.2	2.0	0.1	6%	101%	2%	0%
Littoral coarse sediment	A2.1	15.8	1.4	8.5	3.2	5.3	0.0	9%	54%	33%	0%
Littoral sand and muddy sand	A2.2	891.3	95.7	638.9	649.8	612.5	0.0	11%	72%	69%	0%
Littoral mud	A2.3	232.5	30.1	167.4	173.7	195.7	0.0	13%	72%	84%	0%
Littoral mixed sediments	A2.4	15.0	6.9	11.5	10.4	11.4	0.0	46%	77%	76%	0%
Littoral habitats - Biogenic											
Coastal saltmarshes and saline reedbeds	A2.5	146.1	5.6	74.5	44.8	48.1	0.0	4%	51%	33%	0%
Littoral sediments dominated by aquatic angiosperms	A2.6	5.3	0.0	5.0	4.3	5.2	0.0	0%	94%	99%	0%
Littoral biogenic reefs	A2.7	34.0	6.9	18.4	18.5	14.1	0.0	20%	54%	41%	0%
Features of littoral sediment	A2.8	2.1	0.4	0.7	1.0	1.1	0.0	20%	36%	51%	0%
Sublittoral habitats											
Sublittoral rock and other hard substrata	A4	1151.7	0.1	1.2	0.5	0.0	0.0	2%	32%	0%	0%
Sublittoral sediment	A5	513.3	11.5	216.5	81.2	0.1	12.7	3%	52%	0%	3%
Sublittoral coarse sediment	A5.1	19860.1	105.4	5587.0	1378.9	10.2	293.4	1%	32%	0%	2%
Sublittoral sand	A5.2	9379.2	270.2	4234.9	3307.6	89.6	38.9	3%	49%	1%	0%
Sublittoral mud	A5.3	6593.5	276.8	1113.1	290.2	30.1	1.0	7%	28%	1%	0%
Sublittoral mixed sediments	A5.4	2360.9	14.7	846.9	95.6	0.4	2.2	1%	31%	0%	0%
Angiosperm communities in reduced salinity	A5.5		0.0	9.4	5.4	0.5	0.0	0%	97%	5%	0%
Sublittoral biogenic reefs	A5.6		2.2	14.7	12.3	0.8	0.0	11%	76%	4%	0%
Deep seabed	A6		0.0	0.0	0.0	0.0	0.0				
Deep-sea sand	A6.3		0.0	0.0	0.0	0.0	0.0				
Deep-sea mud	A6.5		0.0	0.0	0.0	0.0	0.0				
Totals		**41377.5**	**840.1**	**13099.2**	**6142.7**	**1058.4**	**348.9**				
			2%	32%	15%	3%	1%				

2.3 Water column processes

The sublittoral seabed habitats described earlier in this report accumulate carbon at different rates. Carbon dioxide may be dissolved directly from the atmosphere into the water column, or it may be respired by organisms within the water column. Organic carbon is fixed within marine organisms and excreted. As particles sink through the water column, they are stripped of their easy-to-digest (labile) compounds, releasing nutrients. This process, termed the biological pump, both sequesters atmospheric carbon and releases nutrients that eventually fuel production. Most of the carbon that sinks below 1,000 m is remineralised (converted back to CO_2) in the water column prior to its deposition on the seafloor, leaving only 1% of the carbon fixed at the surface estimated to be deposited on the seafloor (Lutz *et al*., 2007); thus most of the carbon fixed at the surface is not exported into the deep ocean. The amount of carbon held in organic matter as it descends from surface waters decreases exponentially with increasing water depth (Martin *et al*., 1987), although the rate of decline is location specific. This flux of particles out of the surface waters provides a pathway for carbon capture from the atmosphere and its transfer to the shelf seabed and the deep sea.

The production of organic matter, its transport and its inevitable decay play an important role in shelf seas (such as the Irish Sea) and their contribution to carbon cycles. Dissolved organic matter (DOM) and particulate organic matter (POM) dynamics follow a seasonal cycle in the Irish Sea (Davis *et al.,* 2019). The quantity of OC is largest during the spring phytoplankton bloom and lowest in autumn. Downward fluxes are dominated by POM during bloom events and by DOM during the stratified summer. In terms of partitioning, 92–96% of OC is in the DOM pool throughout and has the potential for off-shelf export of carbon during winter mixing (Davis *et al.,* 2019). The dynamics of organic matter transformation as it descends through the water column are particularly relevant when determining sediment carbon accumulation in offshore areas. These processes are discussed in detail in the relevant sections.

2.4 Intertidal and subtidal macroalgae

2.4.1 Intertidal species

Background and UK context

Canopy-forming fucoids are likely to make the largest *intertidal* contribution to carbon production and loss. Based on habitat suitability modelling this macroalgal group can be found throughout the UK (Yesson *et al*., 2015), with records of seven fucoid species being present along the intertidal rocky shore regions of the study area, namely *Pelvetia canaliculata*, *Fucus spiralis*, *F. vesiculosus*, *F. serratus*, *Ascophyllum nodosum*, *Halidrys siliquosa* and *Himanthalia elongata*. There has been a general assumption that intertidal macroalgae have lower productivity than subtidal macroalgae (i.e., kelp) (Mann, 2000). However, a review of the literature suggests that intertidal fucoids can be highly productive, with values in the range of 4–1,800 g C/m^2/yr (Lewis, 2020). UK estimates of primary productivity are only available for *F. vesiculosus*, *F. serratus* and *A. nodosum*, and are based on data collected from mid and north Wales. Rates of primary production varied across seven study sites for all three species; primary productivity of *F. vesiculosus* was in the range of 166–946 g C/m^2/yr (mean ± SE, 430±106 g C/m^2/yr), that of *F. serratus* was 222–958 g C/m^2/yr (611±124 g C/m^2/yr) and that of *A. nodosum* was 16–70 g C/m^2/yr (49±10 g C/m^2/yr) (Lewis, 2020). The latter values are considerably lower than those previously reported for *A. nodosum* (90–935 g C/m^2/yr) (Brinkhuis, 1977; Lamela-Silvarrey *et al*., 2012), although this probably reflects differences in how individual plants were defined. The site-level variability was not related to differences in wave exposure, as although the sites covered a wave exposure gradient there was no consistent relationship between this and rates of primary production (Lewis, 2020). There have been no published estimates of primary productivity for the other fucoid species in the UK, but such estimates are available from Spain for *F. spiralis* (182.5 g C/m^2/yr), *Himanthalia elongata* (989.2 g C/m^2/yr) and *Pelvetia canaliculata* (351 g C/m^2/yr), and from Denmark for *Halidrys siliquosa* (5.4 g C/m^2/yr). Estimates of fucoid biomass are also restricted to *F. vesiculosus*, *F. serratus* and *A. nodosum*. Values were in the range of 358–634 g C/m^2 (mean ± SE, 536±29 g C/m^2) for *F. vesiculosus*, 241–1,213 g C/m^2 (659±127 g C/m^2) for *F. serratus* and 696–1,649 g C/m^2 (1,033±134 g C/m^2) for *A. nodosum* (Lewis, 2020). These values were derived from between seven and nine sites in mid and north Wales.

Seaweeds are highly sensitive to environmental changes, and their annual growth cycles are responsive to daylight hours (de Bettignies *et al.,* 2018). The distinct seasonal growth cycles result in the production of detritus annually in pulses which usually accompany either weather events, such as storms in autumn or winter, or rapid growth between January and June causing distal material to break off (Lewis, 2020; O'Dell, 2022). There is a consistent biomass of seaweed which usually remains and can be reliably measured. The contribution to long-term carbon storage from fucoid species can be measured as a proportion of the detritus produced (Krause-Jensen and Duarte, 2016).

Information on fucoid detrital production is limited, with information only available for *F. vesiculosus, F. serratus* and *A. nodosum*, based on data collected in mid and north Wales. Fucoids lose biomass via three pathways, namely chronic erosion of blade material (including that caused by grazing), whole plant dislodgement and seasonal senescence of reproductive receptacles. Estimates of fucoid detrital production are based on dislodgement and receptacle senescence, and are therefore probably conservative. Whole plant dislodgement ranged from 79–375 g C/m^2/yr (mean ± SE, 148±43 g C/m^2/yr) for *F. vesiculosus* to 18–636 g C/m^2/yr (215±91 g C/m^2/yr) for *F. serratus* and 41–390 g C/m^2/yr (248±57 g C/m^2/yr) for *A. nodosum* (Lewis, 2020). Based on data collected from one site in mid Wales, receptacle senescence contributed an additional 229, 153 and 139 g C/m^2/yr of detrital material from *F. vesiculosus, F. serratus* and *A. nodosum*, respectively. Combined, detrital production by *F. vesiculosus* contributes on average 377 g C/m^2/yr, that by *F. serratus* contributes 368 g C/m^2/yr and that by *A. nodosum* contributes 387 g C/m^2/yr. These conservative estimates of detrital production are comparable to the amount of detrital material released by *Laminaria hyperborea* (see below). If fucoids lose a similar percentage of biomass via chronic erosion to kelp (*c*. 20%) (Pessarrodona *et al*., 2018) this would mean that they contribute, on average, approximately 452 g C/m^2/yr. Given that *Himanthalia elongata* and *Halidrys siliquosa* have restricted distributions, and *F. spiralis* and *P. canaliculata* are smaller than the other canopy-forming species, it is likely that *F. vesiculosus*, *F. serratus* and *A. nodosum* contribute the most to intertidal macroalgal carbon production and loss (Burrows *et al*., 2021).

Irish Sea and Welsh Coast Region

Values for productivity, biomass and carbon storage by the Fucales in the Region follow those for the whole UK, as described earlier. Summaries of the extent, productivity and biomass of these species are presented in Table 2. Production rates measured by Lewis (2020) were obtained at coastal sites in Wales, so are particularly relevant to the Region.

Table 2. Intertidal macroalgal habitat extent and rates of carbon accumulation used for the Irish Sea and Welsh Coast Region blue carbon assessment. Carbon sequestration is measured as a proportion of the production which is released as detritus annually and exported to sediment stores, and ultimately added to long-term carbon stores. Average carbon density and annual rates of production used in Region estimates are shown in bold type.

Irish Sea and Welsh Coast	43112 km²				**Organic carbon**							
Habitat	Extent (km²)	Component area (km²)	Stock (1000 tC)	Stock (g C/m²)			Production rate (g C/m²/yr)			Total production (1000t C/yr)	Outflux (1000t C/yr)	Source
				min	max	avg	min	max	avg			
Intertidal macroalgae	65.8	65.8	8.0	85	160	122	125	727	378	24.9	2.5	This report
	65.8	65.8	8.8			134 [1]						Walker 1954; Burrows et al 2014
Intertidal rock	72.8	72.8										Habitat Extent Totals
				Stock (g C/m²)			Production rate (g C/m²/yr)					
Species: whole plants				min	max	avg	min	max	avg			
Fucus vesiculosus				358	634	536	166	946	430			Lewis 2020
Fucus serratus				241	1213	659	222	958	611			Lewis 2020
Ascophyllum nodosum				696	1649	1033	20	70	49			Lewis 2020
Ascophyllum nodosum							90	935				Brinkhuis 1977
Fucus spiralis									183			Habitat Review
Himanthalia elongata									989			Habitat Review
Halidrys siliquosa									5			Habitat Review
Average				**432**	**1165**	**743**	**125**	**727**	**378**			
Species: detritus							min	max	avg			
Fucus vesiculosus - all									377			Lewis 2020
Fucus serratus									368			Lewis 2020
Ascophyllum nodosum									387			Lewis 2020
Stock estimates based on biomass measurement												Burrows, unpublished data

2.4.2 Kelp

Background and UK context

Large stipitate canopy-forming brown algae within the order Laminariales are referred to as kelps. The dominant kelps in the UK are *Laminaria hyperborea*, *Laminaria digitata*, *Saccharina latissima*, *Alaria esculenta* and *Sacchoriza polyschides*. The most abundant and therefore dominant foundation kelp species along most of the UK coastline is *Laminaria hyperborea* (Smale *et al*., 2020).

Irish Sea and Welsh Coast Region

The majority of habitat is probably suitable for rocky intertidal and subtidal species along the Northern Irish coastline, with historical observations reported by Schoenrock *et al.* (2020), but large parts of the Welsh coastline also provide suitable habitat (see Figure 3). Only the northern coast of the Isle of Man is unsuitable for kelp. Studies on kelp biomass in the Region are limited, but Smale *et al.* (2016) found that one study site in south-west Wales had significantly lower biomass of *Laminaria hyperborea* forests compared with sites in Scotland and England. Similarly, detritus export from kelp forests in Wales was significantly lower than that in Scotland and England, and was in the range of 98–163 g C/m^2/yr (Smale *et al.,* 2021). Since the available data for kelp forest biomass are limited to a few study sites in Wales, and biomass and detritus production are likely to vary with latitude within the Irish Sea and Welsh Coast Region (Smale and Moore, 2017), national average values were used to estimate biomass and detritus production in the present report.

The extent of kelp habitat in the Region was estimated from a habitat suitability model, further details of which can be found in the English North Sea Blue Carbon Report (Burrows *et al.,* 2021). The model is based on relationships between recorded presence and absence of kelp in Joint Nature Conservation Committee (JNCC) Marine Nature Conservation Review surveys and four environmental predictor variables, namely wave fetch, depth, water-column chlorophyll a concentration (from satellite ocean colour data) and sea surface temperature (see Figure 3). Given the known limitations on kelp habitats, primarily the presence of suitable rocky habitat at depths suitable for growth, the habitat extent and consequent estimates of biomass and sequestration capacity are likely to be upper limits. Values used for sequestration rates were derived from the literature and from averages of published rates documented by Burrows *et al.* (2021) in the English North Sea Blue Carbon Report and by Burrows *et al*. (2024a) in the English Channel and Western Approaches Region report. The data that were used to estimate the contribution of kelp are summarised in Table 3.

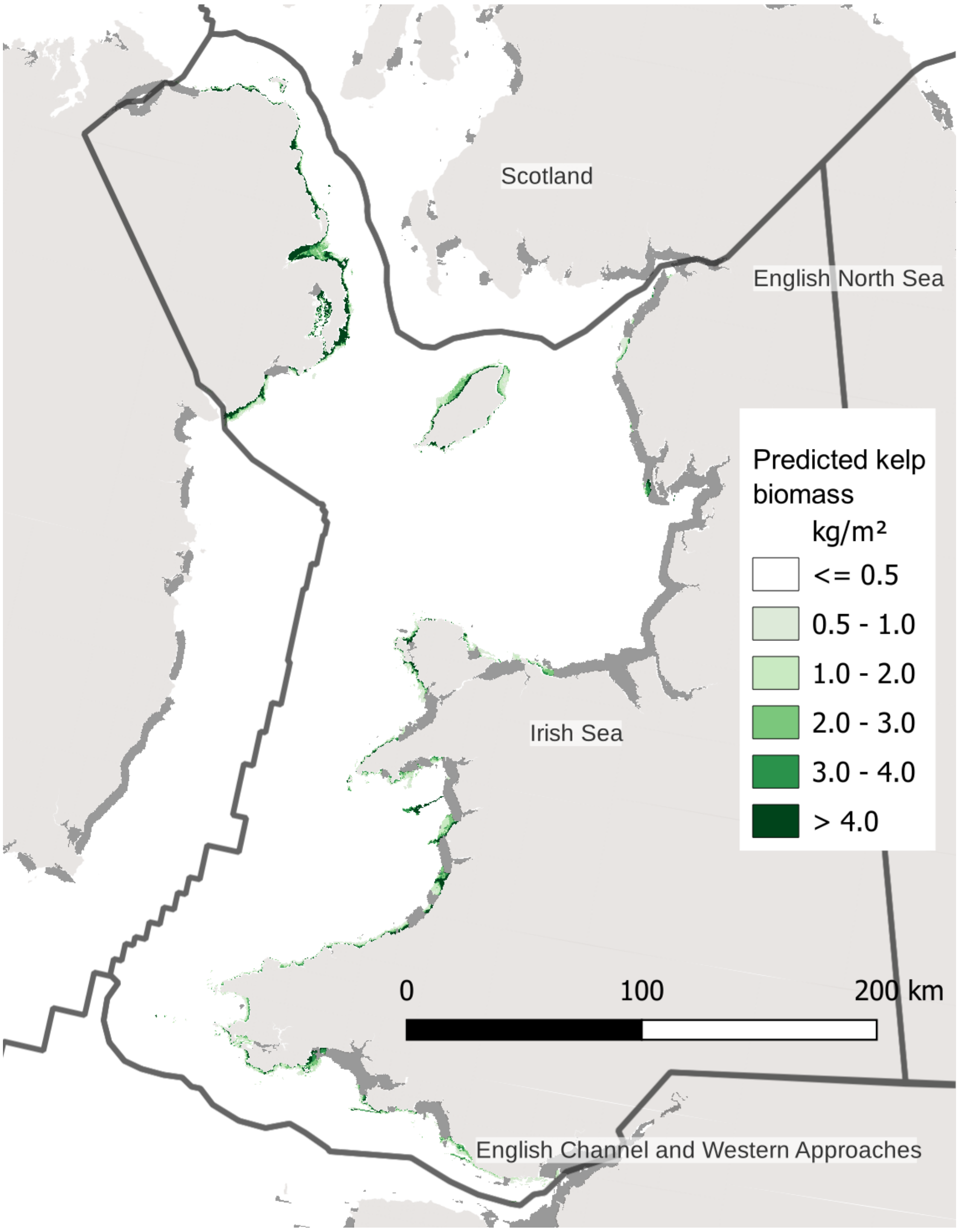


Figure 3. Predicted kelp biomass distribution in the Irish Sea and Welsh Coast Region. Coastal areas shown in dark grey are adjacent to areas of intertidal sediment, and were removed from the model estimates as they were considered unlikely to be suitable for kelp.

Table 3. Kelp habitat extent and rates of carbon accumulation estimated for the Irish Sea and Welsh Coast Region. Carbon sequestration is measured as a proportion of the production which is released as detritus annually and exported, remineralised (converted back to CO_2) or buried and stored long term. Values used in the ecosystem summary (see Table 15) appear in the second row of the Table.

Habitat	Extent (km²)	Component area (km²)	Standing stock (1000 t)	Stock (g C/m²)			Production rate (g C/m²/yr)			Total production (1000t C/yr)	Outflux (1000t C/yr)	Source and comments
Irish Sea and Welsh Coast Region	43112	1477	877.3			594			332	490.8	49.1	Habitat Review average rate * [model area > 0.5kg/m² w/w]; Queiros et al 2019
Kelp beds		1477	204.0			138			685	490.8		From *L. hyperborea* habitat model: average stock density x extent
									685	1012.0		Burrows *et al.* (2014) for average kelp production
						594			**332**		**301**	Habitat Review averages
Fixation from growth rates				min	max	avg	min	max	avg	Proportion of stock		
L. hyperborea				208	1709	**640**	166	738	**340**	0.9		Smale *et al.* (2020)
L. hyperborea									**330**			This review (Section 2.2)
L. digitata				79	278	**179**	135	402	**262**	0.1		King *et al.* (2020)
L. digitata						**403**						Gevaert *et al.* (2008)
L. digitata									**480**			This review (Section 2.2)
Saccharina latissima									**290**			This review (Section 2.2)
Detritus production												
L. hyperborea							104	568	**301**			Smale et al 2021

2.4.3 Fate of macroalgal detritus

Most seaweed-dominated habitats export carbon as detritus, and an understanding of the fate of this material is important, given the quantities involved. Macroalgae are highly productive, and much effort has been made to understand the productivity of key species (see Table 3 and Table 4). Long-term carbon storage (beyond that of living biomass) is largely governed by the production, transport, degradation and eventual sedimentation of the detritus produced by macroalgal ecosystems (Krumhansl and Scheibling, 2012; Trevathan-Tackett *et al*., 2015; Krause-Jensen and Duarte, 2016). Macroalgae grow on hard substrates where carbon burial is precluded, and they do not have root systems to stabilise sediments, so carbon storage in this blue carbon habitat is different from that in seagrass and saltmarsh systems, and largely dependent on the annual production of large amounts of detritus. In south-west England the amount of macroalgal-derived carbon transferred to sediments has been estimated to be 9 g C/m^2 /yr (Queirós *et al*., 2019).

Table 4. Estimates of primary productivity of three key macroalgal species in the UK. From O'Dell (2022).

Species	**Productivity (g C/m²/yr)**	**SD**	**SE**	***n*[1]**	**References**
Laminaria digitata	480	550	120	20	Gunnarsson, 1991; Krumhansl and Scheibling, 2012; Smith, 1988
Laminaria hyperborea	330	430	7	42	Kain, 1977; Gunnarsson, 1991; Jupp and Drew, 1974; Luning, 1969; Pessarrodona *et al*., 2018; Sjotun *et al*., 1995; Smale *et al*., 2016
Saccharina latissima	290	40	11	12	Borum *et al*., 2002; Brady-Campbell *et al*., 1984; Krumhansl and Scheibling, 2012; Johnston *et al*., 1977

[1] *n* refers to the number of data points used to calculate mean values, standard deviation (SD) and standard error (SE).

2.4.4 Maerl

Background and UK context

Maerl is a term for unattached coralline red algae, including the species *Phymatolithon calcareum*, *Lithothamnion corallioides* and *Lithothamnion erinaceum*, albeit with ongoing unpublished genetic studies potentially identifying new species. Maerl beds are made up of live or dead thalli or a varying mixture of both, and can form extensive beds at depths of up to 40 m (Hall-Spencer *et al.,*, 2010). These habitats have a complex three-dimensional structure , and are thus analogous to seagrass beds or kelp forests (Hall-Spencer, 1999). They have rich biodiversity and act as nursery grounds for commercially important species of fish, crabs and scallops , including queen scallops (*Aequipecten opercularis*) (Kamenos *et al*., 2004a, 2004b). Maerl is absent from large areas of the UK, including most of the North Sea, the Irish Sea and the eastern English Channel.

UK maerl bed distribution has been described by Hall-Spencer *et al*. (2008). Maerl beds around the coasts of the UK are nearly all on exposed west coasts, where there are no major rivers carrying large quantities of suspended sediment. In Scotland, maerl is widespread along the west coasts, in the Western Isles and in Orkney and Shetland. It is also present on the north coast (Loch Eriboll), but is absent from the east coast of Scotland.

Maerl deposits act as a longer-term store for OC and IC and calcifying biota. Maerl species can be considered to be a key element of carbon and carbonate cycles in the shallow coastal waters where they occur. The rate of maerl deposit accretion is generally slow (0.25 mm/yr); however, beds can be extensive. Scottish species-specific accretion rates were found to be in the range of 420–1,432 g $CaCO_3$ /m^2/yr in a study by Freiwald and Henrich (1994), cited in Burrows *et al*. (2014). Available irradiance is the main factor influencing the primary production of maerl, and accounts for more than 94% of the carbon fluxes for assessed maerl beds (Martin *et al*., 2006). As a consequence, variations in irradiance that result from anthropic impacts and climatic changes (e.g., albedo, variations in water height or turbidity) could exert an influence on maerl.

Calcification and primary production responses to irradiance in *L. coralloides* were measured in summer 2004 and winter 2005 in the Bay of Brest (Martin *et al*., 2006). Net primary production reached 1.5 µmol C/g dry wt/h in August, and was twice as high as in January and February. Maximum calcification rates (accumulation of $CaCo_3$) ranged from 0.6 µmol/g dry wt/hr in summer 2004 to 0.4 µmol/g dry wt/hr in winter 2005. Estimated daily net production and calcification reached 131 µg C/g dry wt and 970 µg $CaCO_3$/g dry wt, respectively, in summer 2004, and 36 µg C/g dry wt (production) and 336 µg $CaCO_3$/g dry wt (calcification), respectively, in winter 2005. The net primary production of *L. coralloides* populations in shallow waters was estimated to be 10–600 g C/m^2/yr, depending on depth and algal biomass. The mean annual calcification of *L. coralloides* populations ranged from 300 to 3,000 g $CaCO_3$ /m^2/yr.

Precise data on the proportion of live or dead maerl deposits within the beds is scarce in the UK. However, live maerl deposits (which can range from 5% to 100% of individuals on the surface layer and below) on the west coast of Scotland can reach 30-40 cm thickness and overlie dead deposits residing significantly deeper (Kamenos, 2010; Burrows *et al.,* 2014). Burrows *et al*. (2014) applied an annual IC sequestration rate of 0.074 kg/m^2 for the purpose of their Scottish study (from Kamenos *et al.,* 2004a; Kamenos, 2010). Sequestration rates used in this study are from multiple sources (see Table 5).

In similar environmental conditions, maerl bed productivity is approximately one-third that of seagrass beds (when compared over a similar proportionate surface area). Maerl communities are therefore relatively productive compared with other temperate coastal habitats (Martin *et al*., 2005; Hall-Spencer *et al*., 2008), justifying their consideration as blue carbon ecosystems.

Table 5. Storage and sequestration values used in Welsh and Scottish estimates of carbon storage and sequestration by maerl beds.

Reference	Parameter	Value
Armstrong *et al*., 2020	Biomass of live maerl, *Phymatolithon calcareum*	90 g/m^2* (20% of the value applied by Burrows *et al*. (2014) due to lower productivity)
Armstrong *et al*., 2020	Soil carbon density	12,400 g/m^2 (top 60 cm, for live and dead maerl beds)
Armstrong *et al*., 2020	Sequestration	9.5 g m^2/yr**
Martin *et al*., 2006	Net primary production	10–600 g/C/m^2/yr
Martin *et al*., 2006	Mean annual calcification	300–3,000 g $CaCO_3$ m^2/yr

* This was 20% of the value applied by Burrows *et al*. (2014), as Welsh beds are thought to consist of *Lithothamnion glaciale*, and also as Welsh beds are considered to be degraded.

** This represents the minimum sequestration rate quoted for *P. calcareum* by Burrows *et al*. (2014).

Irish Sea and Welsh Coast Region

In Wales, maerl is restricted to a small area of Milford Haven and small patches around the Pembrokeshire Islands and Lleyn peninsula, which are all currently classed as ‘degraded’ (Tillin *et al*., 2020). Therefore it is unlikely that Welsh maerl contributes substantially to carbon sequestration in Welsh waters. There are several records of maerl (point-source data) around the Isle of Man and along the coast of Northern Ireland (Hall-Spencer *et al*., 2010) (see Figure

4), but without accurate extents of these habitats their contribution to carbon storage would be highly uncertain and probably insignificant. Where point-source data do exist, this does not necessarily imply that a maerl bed is present, and it may relate to a single observation, or just a few.

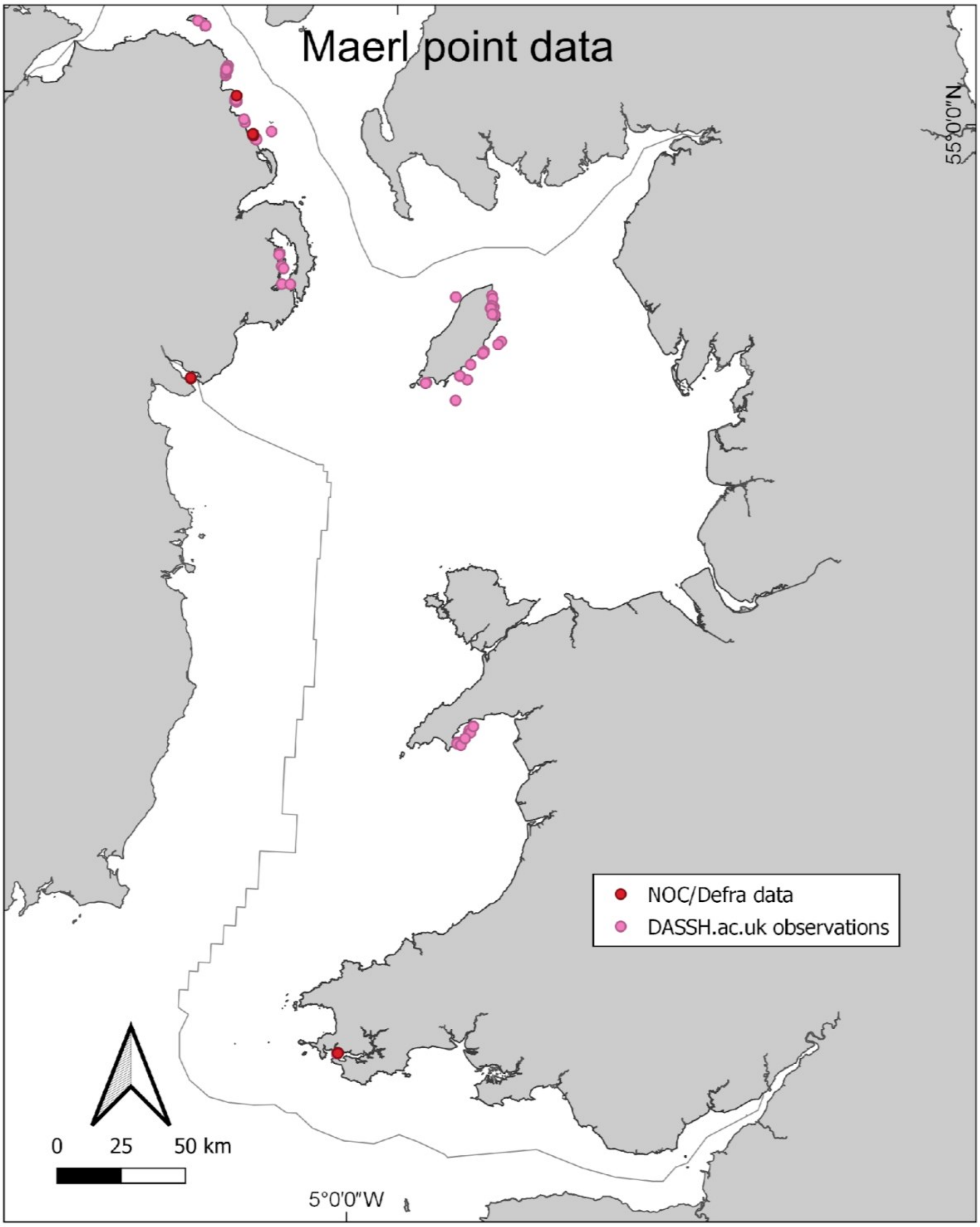


Figure 4. Point-source data for maerl beds from the National Oceanography Centre (NOC) database and from observations recorded in the Archive for Marine Species and Habitats Data (www.DASSH.ac.uk).

2.5 Saltmarsh

2.5.1 Background and UK context

Coastal saltmarshes may be defined as areas that are vegetated by halophytic (salt-tolerant) herbs, grasses or low shrubs, and which border saline water bodies (Adam, 1990). Saltmarshes form in low-energy or sheltered environments with shallow water, and the rate of formation depends upon the degree of exposure, the topography of the near-shore seabed and the supply of suspended sediment (Long and Mason, 1983). Saltmarsh extent in natural conditions is broadly governed by a combination of physical parameters, most importantly sediment supply, tidal regime, salinity, wind and wave action. A relatively flat intertidal topography that slopes gradually toward the intertidal channels provides the most suitable location for saltmarsh development (Zedler, 1984). As a result of the dynamic nature of saltmarsh habitats there can be high rates of carbon turnover, especially at lower shore heights, which are often in the earlier stages of succession and have less vegetative cover.

Within a saltmarsh habitat complex, halophytic plant species and communities display a transition from marine to terrestrial habitat. There is general agreement that the main factors affecting the zonation of halophytic plant species within a saltmarsh habitat relate to frequency of tidal inundation and the associated effects of salinity and tidal scouring (Austin *et al.*, 2021). Each species has a different tolerance to tidal flooding, and as a result different species have different, although often overlapping, vertical ranges. Different communities are therefore apparent at different tidal elevations. At higher shore elevations, which can be dominated by floristically diverse assemblages, soil carbon content can be higher and turnover rates are slower.

Saltmarsh habitats are considered to be net carbon sinks that are formed through capture of CO_2 from the surrounding air and water column by the plants that subsequently store this carbon in their roots and rhizomes. At the same time, saltmarsh plant roots physically bind together soil particles and encourage rhizome-inhabiting microbes to do the same, trapping organic material (Ford *et al.*, 2016). The exudation of captured carbon and organic material into the soil creates an anaerobic, carbon-rich sediment (Reid and Goss, 1981, cited in Ford *et al.*, 2016). This has the ability to accumulate carbon without reaching saturation (i.e., anaerobic conditions slow the rate of decomposition) and can potentially store carbon over millennial timescales (Stewart and Williams, 2019).

As these habitats are dynamic, and can be subject to die-back and physical remobilisation at intervals of decades or centuries (Burrows *et al.*, 2014), including significant changes in extent through erosion and deposition (Ladd *et al.,* 2019), they may not be capable of storing carbon over significant timescales (over 100 years). Carbon sequestration rates vary between complexes, with variability related to numerous factors, including hydroperiod (time spent submerged), salinity, nutrient input (i.e., from pollution) and suspended sediment supply (Nelleman *et al.*, 2009). Substrate type and thickness are also important factors in saltmarsh sequestration potential, with clay soils widely recognised as good stores of OC due to the efficient adsorption of organic carbon compounds to clay particles (Ford *et al.*, 2019). Plant community composition and plant diversity are also important, as they largely determine root properties such as biomass, sediment turnover and carbon exudation rate. Ford *et al.* (2016) suggest that species-rich saltmarshes have a reduced soil erosion rate, and may therefore sequester carbon for longer than less species-diverse marshes. Similarly, the relationship between soil stabilisation and plant diversity was found to be stronger in erosion-prone sandy soils compared with resilient clay soils (Ford *et al.*, 2016).

. Sequestration rates in UK saltmarsh are in the range of 64–219 g $C/m^2/yr$ (Adams *et al.*, 2012), with typical figures of around 120–150 g $C/m^2/yr$ (Beaumont *et al.*, 2014). Burrows *et al.* (2014) applied a single value of 210 g $C/m^2/yr$ for their Scottish study from the global review by Chmura *et al.* (2003).

It has been established that saltmarsh restoration provides a sustained sink for atmospheric CO_2 (Burden *et al.*, 2013). Based on 36 samples collected from nine saltmarshes in Essex, mean above-ground vegetative biomass was estimated to be 282±234 g C/m^2 (Beaumont *et al.*, 2014). Based on data from the same sites, estimated mean soil bulk density was 0.448±0.03 g/cm^3, of which carbon soil density was 0.0244 g/cm^3 and 0.0116 g/cm^3 (based on soil carbon content of 5.45% and 2.6%) for soils much thicker than sublittoral sediments at 0–30 cm and 30–100 cm depth, respectively (Beaumont *et al.*, 2014). In the region, soil carbon was in the range of 1–5% on the mudflat and lower saltmarsh dominated by pioneer species, and 3–5% in the more vegetated middle and higher saltmarsh (Andrews *et al.*, 2008).

Marsh accretion rates on the east coast of England have been estimated to be in the range of 62–196 g C/m^2/yr, with rates differing between high and low marsh, but not in a consistent manner (Callaway *et al.*, 1996). Although Callaway *et al.* (1996) do not provide carbon accumulation rates, these values were based on the total mineral and organic accumulation rates, with carbon accumulation rates based on a soil carbon content of 5.45% estimated for east coast sediments at depths of 0–30 cm (Beaumont *et al.*, 2014). The rates reported by Callaway *et al.* (1996) for marsh accretion are similar to those estimated by others for the UK, namely 66–196 g C/m^2/yr (Adams *et al.*, 2012; Burrows *et al.*, 2014; Cannell *et al.*, 1999; Chmura *et al.*, 2003), and to global estimates, namely 151 g C/m^2/yr (Duarte *et al.*, 2005).

There is a differential in carbon sequestration between natural and restored saltmarsh habitat, with the average carbon density of natural ecosystems being higher (range 12.7–69 kg C/m^2; n = 85; average 40.3 kg C/m^2) than that of restored saltmarshes (10.125 kg C/m^2; n = 12; average 18.6 kg C/m^2; Gregg *et al.*, 2021). However, it is suggested that the time that has elapsed since restoration plays a part in determining the storage capacity of the saltmarsh in question. In addition to time since restoration, other factors such as management practice (including grazing) and the type of soil in the area can also have an impact on the storage capacity of the saltmarsh (Gregg *et al.*, 2021).

2.5.2 Irish Sea and Welsh Coast Region

Many of the sheltered, upper estuarine or sea lough areas in the Irish Sea and Welsh Coast Region have saltmarsh habitats. These are particularly abundant along the north-west English coast and the south coast of Wales. Strangford Lough in Northern Ireland has extensive saltmarsh, but these shapefiles are grouped with other habitats, and so may overestimate the true extent of saltmarshes along the Northern Irish coast (see Figure 5). To overcome this, the present report uses a figure from a published review of blue carbon habitats within the Irish Sea and Welsh Coast Region (Strong *et al.,* 2021), which estimated that there are 31.1 km^2 of saltmarsh in Northern Ireland.

A Welsh study conducted in 2015 by Ford *et al.* (2019) sampled 23 saltmarsh sites to determine carbon stores. Plant and soil characteristics were analysed for each site, and the carbon store was determined for each of the sampling locations (51 in total across the 23 sites). Values from the study by Ford *et al.* (2019) contributed to the store estimates used in this report (see Table 7). Saltmarshes in Wales and on the west coast of the UK generally have a shallow organic-rich clay layer (less than 1 m) underlain by sandy substrate, and are frequently grazed by livestock (May and Hansom, 2003, cited in Beaumont *et al.*, 2014), whereas the marshes of the south and east UK coasts are characterised by a deep (more than 10 m) organic-rich clay substrate, and are most commonly not grazed (Beaumont *et al.*, 2014).

A recent study commissioned by Natural Resources Wales (Armstong *et al.*, 2020) used the following values:

- Biomass density: 0.21 kg/m^2. This has been taken from the report by Burrows *et al.* (2014), prepared for Scottish Natural Heritage (SNH) for Scotland.

- Soil carbon density: 4.2 kg/m^2 (top 10 cm). This is the average of values reported for 51 Welsh samples taken across 23 saltmarshes (see Ford *et al*., 2019; supplementary material).
- Sequestration: 0.084 kg/m^2/yr. This has been calculated using a 2-mm depth proportion of the soil carbon density value.

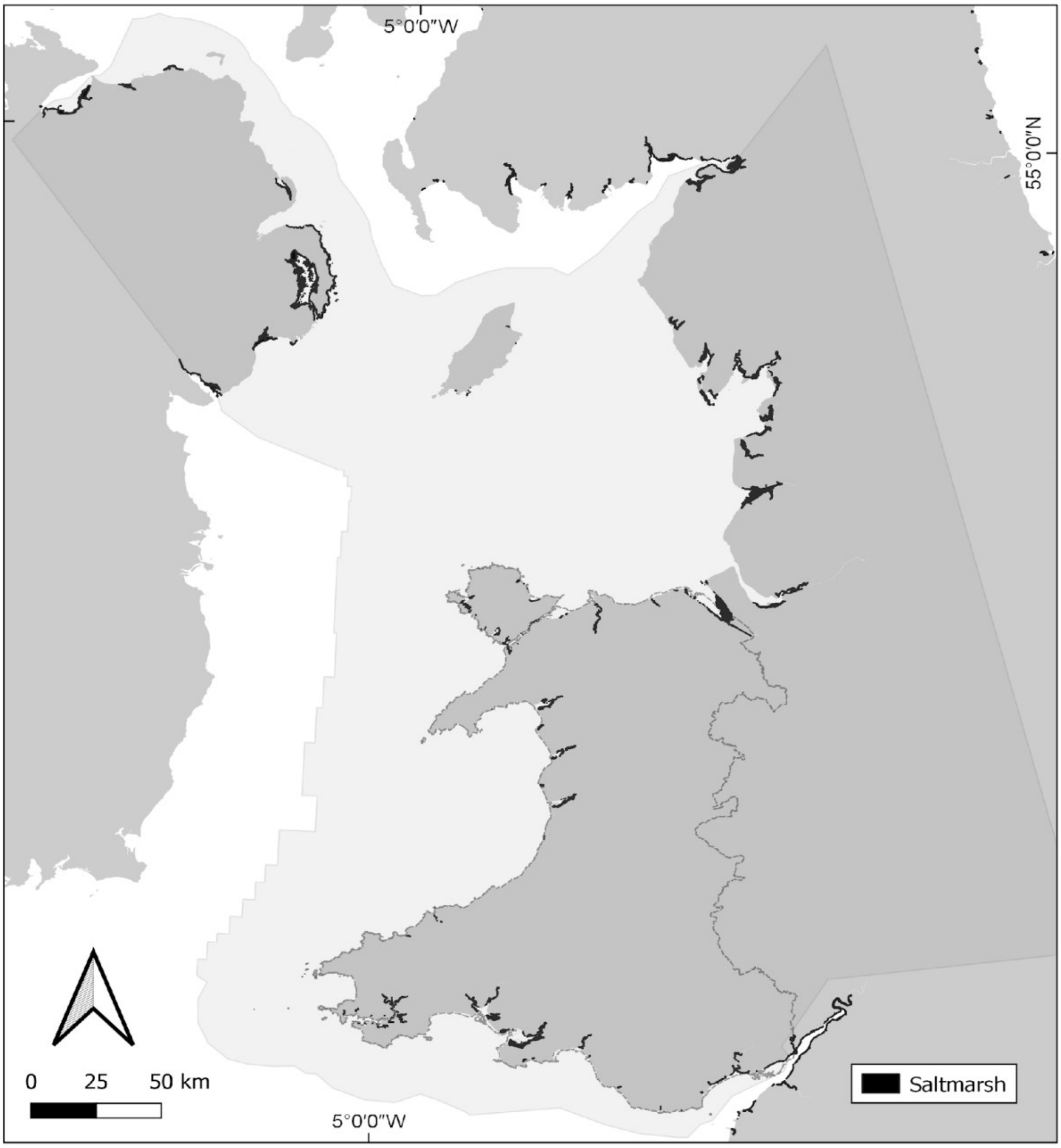


Figure 5. Saltmarsh extent for the coasts of England (Environment Agency) and Wales (Natural Resources Wales) in the Irish Sea and Welsh Coast Region. Northern Ireland listed areas that contain saltmarsh have been included with the caveat that some of the regions are designated for multiple features and probably overestimate the extent. The Isle of Man Territorial Seas saltmarshes are also included. Data sources are listed in Annex 1.

2.5.3 Carbon storage

Saltmarsh zonation extents for the English section of this report are defined by plant type. The Welsh, Northern Ireland and Isle of Man coasts are all included (see Table 6). The largest area of saltmarsh in the Irish Sea and Welsh Coast Region in England is in the low-mid zone, and the total extent in England is 124 km^2. The saltmarsh extent in Wales is 57.5 km^2, and that in the Isle of Man is 0.074 km^2.

Table 6. Extent of each zone in saltmarshes from different agency data across the Irish Sea and Welsh Coast Region.

Country (and by type)	*km^2*	*Source*
England	**124.3**	EA Shapefile cut by BC region
Mid-Low	74.6	
Spartina	2.5	
Unclassified	10.4	
Pioneer	4.1	
Upper Marsh	32.5	
Reedbeds	0.2	
Wales	**57.5**	modified from Armstrong et al., (2020) for NRW
Northern Ireland	**31.6**	Strong et al., (2021)
Isle of Man	**0.074**	IoM Shapefiles from Rowan Henthorn IOMBCF

Rates of carbon accumulation for saltmarshes are taken from the habitat reviews in Section 2.4 and summarised in Table 7.

Table 7. Saltmarsh habitat extent, organic carbon (OC) store and storage rates used for the Irish Sea and Welsh Coast Region from England (Environment Agency), Wales (Natural Resources Wales), Northern Ireland (Strong et al.*, 2021) and the Isle of Man Territorial Seas.*

Habitat	Extent (km²)	Component area (km²)	Stock (OC 1000 t)	Stock density (g C/m²)			Production rate (g C/m²/yr)			Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)			Storage capacity (1000t C/yr)	Source
				min	max	avg	min	max	avg				min	max	avg		
Saltmarshes: vegetation		213.4	932.1	48	516	282							62	196	129.0	120.2	Habitat Review (Callaway et al 1996)
Saltmarshes: soil		**213.4**	**932.1**	1270	6900	4085										120.2	EA Saltmarsh Extent dataset; Gregg et al 2021; NRW Extent data; NI extent from Strong et al (2021); IoM data from pers comms (R. Henthorn IoMBCF)
Saltmarshes: soil		213.4	932.1	1270	6900	4085										120.2	Natural England Open Data
Saltmarshes: vegetation		213.4					42	235	138	29.5	2.9	117.3					Kirwan et al 2009, assuming d/w 25% C
Stock estimates				Stock (kg C/m³)													
Natural saltmarsh				12.7	69	40.9											Gregg et al 2021
Regenerated saltmarsh				10.1	25	17.6											Gregg et al 2021

2.6 Seagrass beds

2.6.1 Background and UK context

Seagrasses in the UK (*Zostera marina, Zostera noltii* and the salt-tolerant tasselweed *Ruppia maritima*) can play an important role in carbon sequestration. In other parts of the world seagrass beds act as net sinks of carbon (in the Mediterranean, notably *Posidonia* species) (Duarte and Cebrián, 1996; Duarte *et al*., 2010). The contribution of seagrasses to global oceanic carbon storage has been quantified in several recent studies, but that research focused on only a few species and sites (Dahl *et al*., 2016; Greiner *et al*., 2013; Gullström *et al*., 2018; Macreadie *et al*., 2013; Miyajima *et al*., 2015; Röhr *et al*., 2016; Serrano *et al*., 2014). There are some caveats associated with this global estimation, however, largely due to the high rates of below-ground accumulation of carbon in certain species which are not found in the UK, such as *Posidonia oceanica*, and differences in environmental conditions (Röhr *et al.*, 2018).

Seagrass beds sequester OC in shoots, leaves and below-ground rhizomes, and as seagrass detritus accumulated in the soil. Non-seagrass carbon is deposited mainly from the water column (suspended POC) (Kennedy *et al.,* 2010). This process is enhanced by the presence of the seagrass canopy and its effect in slowing current flow over the sediment surface (Gacia *et al.,* 2002; Hendriks *et al.,* 2008). Organic carbon derived from macroalgae and phytoplankton is much more labile than seagrass-derived OC, especially compared with below-ground biomass (Enriquez *et al.,* 1993; Klap *et al.,* 2000; Nielsen *et al.,* 2004). Yet, once incorporated within the soil compartment, where low oxygen levels inhibit microbial activity (Trevathan-Tackett *et al.,* 2017), remineralisation of allochthonous OC is reduced, leading to a significant contribution to the long-term OC deposits that develop in seagrass soils (global average of 50%) (Kennedy *et al.,* 2010).

Seagrasses export a substantial portion of their primary production, in both particulate and dissolved organic form, but the fate of this export production remains unaccounted for in terms of seagrass carbon sequestration. Available evidence on the fate of exported seagrass carbon (Duarte *et al*., 2005) indicates that this represents a significant contribution to carbon sequestration, both in sediments outside seagrass beds and in the deep sea. The reported evidence suggests that the contribution of seagrass beds to carbon sequestration has been underestimated by only including carbon burial within seagrass sediments (Duarte *et al*., 2005).

Garrard and Beaumont (2014) estimated that seagrass beds in the UK have a mean biomass of 1.61 t C/ha, using data reported from previous studies conducted in different geographical areas. Carbon storage densities in the upper 50 cm of sediment under *Z. marina* and *Z. noltii* were found to be in the range of 22.7 t C/ha and 107.9 t C/ha, with a mean of 57 t C/ha, across seven sites in Scotland (Potouroglou, 2017). Based on these figures the total estimated carbon store in the top 50 cm of seagrass sediment is 91,200 t C across the whole of Scotland.

Carbon sequestration rates of seagrass beds in the UK were estimated to be 2,500 t C/yr by Luisetti *et al.* (2019) and 24,000 t C/yr by Green *et al.* (2021). These estimates are based on frequently used accretion rates in the literature (low rate, 0.044 cm/yr; medium rate, 0.202 cm/yr; high rate, 0.42 cm/yr), with medium rates of carbon accumulation (0.024 Mt C/yr) being used to estimate average annual carbon accumulation (Duarte *et al.,* 2013; Lavery *et al.,* 2013; Macreadie *et al.,* 2013; Miyajima *et al.,* 2015; Röhr *et al.,* 2018). Similar estimates have been made for the carbon sequestration capacity for Scotland (0.0013 Mt C/yr) (Burrows *et al.,* 2014). These estimates relied on values of carbon sequestration for seagrass beds of varying species, from the north-east Atlantic (Fourqurean *et al.,* 2012) and the Mediterranean Sea (Duarte *et al.,* 2005).

Seagrasses are found around the coast of the UK in sheltered areas such as harbours, estuaries, lagoons and bays. *Zostera marina* and *Z noltii* are the most abundant seagrass species found in the UK, with *Z. marina* being the dominant species and occurring predominantly in the sublittoral, whereas *Z. noltii* occurs intertidally (Wilkinson and Wood, 2003). A wasting disease was the cause of a drastic reduction in seagrass beds in the UK in the 1930s. The subsequent recovery has been hampered by increased human disturbance, such as pollution and physical disturbance from dredging, use of mobile fishing gear and coastal development. Seagrass beds are estimated to cover 8,493 ha (84 km^2) in the UK (Green *et al.,* 2018, 2021). Dense beds of seagrass tend to develop in sheltered areas, but in more exposed sites the beds are usually smaller, patchier and more susceptible to storm damage. Seagrass beds are spatially dynamic, with advancing and leading edges, causing changes in coverage. The beds expand either through vegetative growth from shooting rhizomes that have survived the winter, or sexually, by production of seed. Subtidal *Z. marina* beds in the UK are perennial, and some are believed to persist almost entirely as a result of vegetative growth rather than reproduction by seed. Growth of individual plants occurs during the spring and summer.

The total mapped areal extent of contemporary seagrass records (post-1997) from an OSPAR dataset, the European Union Water Framework Directive (WFD) dataset, and all other contributors includes 47 surveys spanning 20 years, 79% of which are from the last 10 years (Green *et al*., 2021). In total, the data confirm the presence of 8,493 ha of seagrass in the UK (see Table 8). The occurrence of seagrasses is not uniform. Half of all mapped seagrass occurs in the Scottish Highlands (24%), Devon (16%), and Northern Ireland (14%). Seagrass extents range from patches of less than 1 m^2 to beds of up to 1,200 ha. The average area of individual seagrass beds is 2.64±32.22 ha. The contemporary data represent the minimum area of seagrasses in the UK, since some beds have certainly gone unreported, as is demonstrated by the recent discovery of extensive beds in Mount's Bay (east of Penzance, Cornwall).

Table 8 Seagrass extents in UK regions. From Green et al. *(2021).*

Location	Area ha	% of total
Scottish highlands	2,056	24.21
Devon	1,392	16.39
Northern Ireland	1,810	14.44
Hampshire and Isle of wight	714	8.41
Northumbria	680	8.01
South Wales	460	5.42
Dorset	372	4.38
Scilly Isles	196	2.31
North Wales	172	2.03
Suffolk, Essex, and Kent	170	2.00
Cornwall	166	1.95
East Scotland	108	1.27
West Wales	90	1.06
Cumbria	65	0.77
Norfolk	42	0.49
Total	**8,493**	

Data present total known areal extent of seagrass in the United Kingdom by region, including relative contribution to the total mapped area.

2.6.2 Irish Sea and Welsh Coast Region

Within the Irish Sea and Welsh Coast Region, datasets from Wales (Natural Resources Wales), England (Natural England) and Ireland (NI Portal, DAERA) were downloaded (for data sources, see Annex 1). Initial estimates of seagrass shapefiles from the Isle of Man government were also provided for this study. The shapefiles were merged, clipped to the extent of the Irish Sea and Welsh Coast Region, and the surface area was extracted from the resulting shapefile.

Polygon data show beds in south-west Wales, Anglesey, Holy Island and Menai Strait, and around Walney Island (see Figure 5). Meadows of *Zostera noltii* have been present in Milford Haven in Wales for some time and are persistent, despite it being a heavily industrialised area

(Bertelli *et al*., 2018). In the English part of the Irish Sea and Welsh Coast Region there is ongoing mapping of seagrass meadows, and an additional dataset from the Cumbria Wildlife Trust was provided which includes *Z. noltii* patches that were mapped in 2022 along the Ravenglass Estuary in Cumbria, which resulted in a further 0.4 km^2 of seagrass being added to the total. There are significant seagrass meadows in Strangford Lough on the east coast of Northern Ireland, and on the west coast of Lough Foyle close to Londonderry (see Figure 5), as well as multiple patches around the coast. The Isle of Man has to date mapped five main areas with seagrass meadows. Merging all areas of known seagrass meadows in the Region gives an estimated total area of 26 km^2 (see Figures 6 and 7).

Seagrass meadows are still being discovered in the UK, and work continues to map and improve modelled estimates of their true extent (Bertelli *et al.,* 2023).

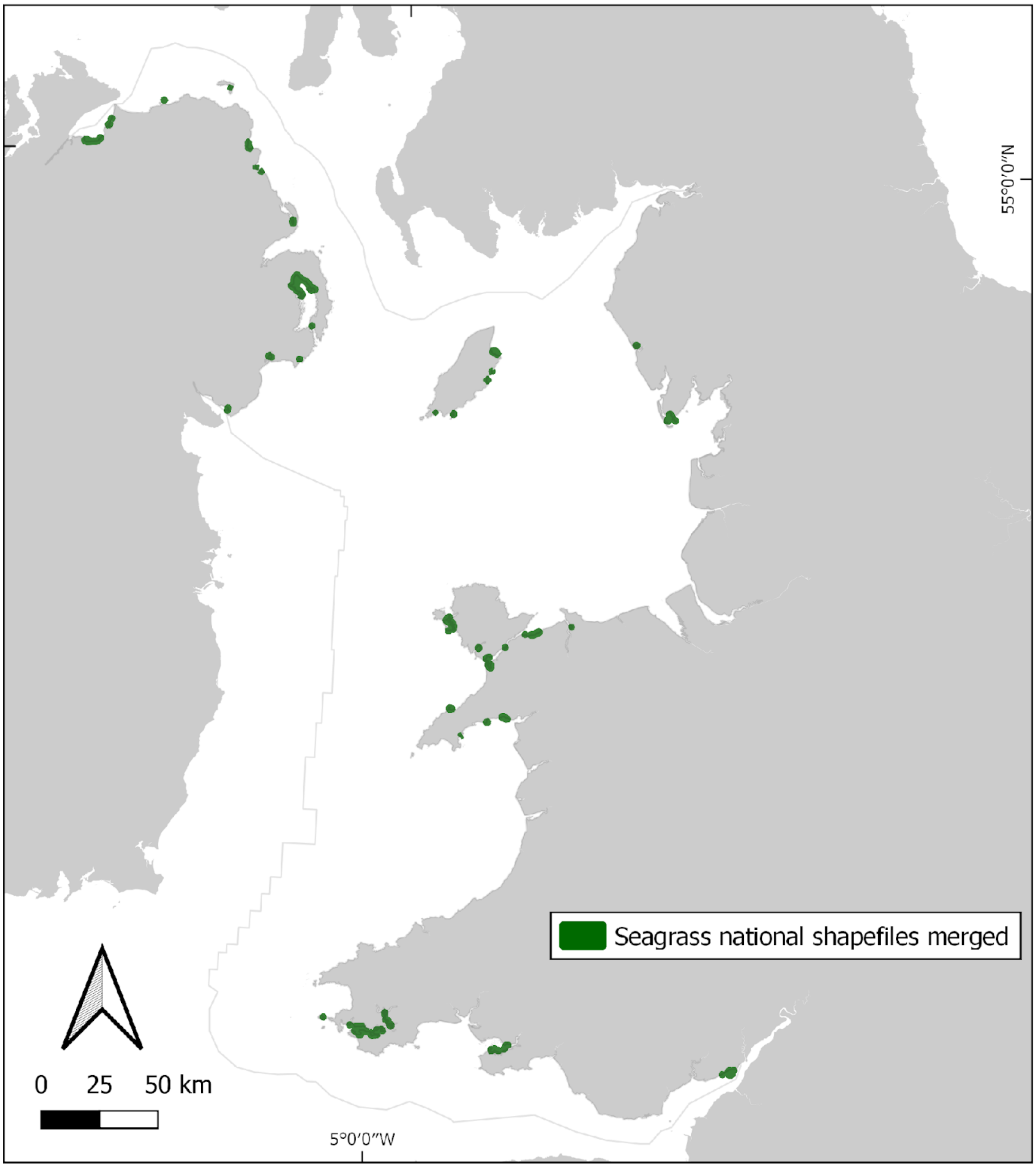


Figure 6. Merged available extents of seagrass beds from the different national archives within the Irish Sea and Welsh Coast Region. Seagrass shapes are not to scale.

Figure 7. Locations of intertidal and subtidal seagrass beds in the Irish Sea and Welsh Coast Region: (a) Barrow in Furness; (b) Holy Island, Anglesey; (c) Pembroke; (d) Menai Straits, Anglesey. From the Natural England habitat polygon database (see Annex 1 for data source).

2.6.3 Carbon storage

Combining the areas of seagrass that have been mapped in the Irish Sea and Welsh Coast Region gives a total extent of 26 km^2. Using the methods described earlier, the total storage capacity of seagrass beds in the area is estimated to be 2,600 t C/yr (see Table 9), this figure being obtained by multiplying the total area of seagrass (26.0 km^2) by the average rate of carbon accumulation in seagrass beds (100.4 g C/m^2/yr).

Table 9. Seagrass habitat extent and rates of organic carbon accumulation used for the Irish Sea and Welsh Coast Region.

Habitat	Extent (km²)	Component area (km²)	Standing stock (1000 t)	Stock (g C/m²) (<0.3m depth)			(<0.1m)	Production rate (g C/m²/yr)			Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)			Storage capacity (1000t C/yr)	Source
				min	max	avg	avg	min	max	avg				min	max	avg		
Irish Sea and Welsh Coast Region	43112		0.0	2940	11402	**7171**	**2390**											
Seagrass		5.3	12.6														0.53	Natural England Blue Carbon Data
		26.0	62.1														2.61	NE plus Isle of Man and Northern Ireland
		7.2	17.2											10.5	48.3	100.4	0.72	Habitat Review
		5.3								274	7.1	0.7						from increase in dry mass of *Zostera marina*; Godshalk and Wetzel, 1978; Sand-Jensen, 1974

Stock estimates	Stock (t C/ha)			Accumulation (cm/yr)				
	min	max	avg	low	med	high	avg	
Seagrass	29.4	114.0	71.7	0.0440	0.2020	0.4200	0.2220	Green *et al.*, 2018, 2021; Luisetti *et al.*, 2019
			48.7					Fourqurean *et al.*, 2012 (North Atlantic)
	22.7	107.8	65.3					Scotland (Potouroglou, 2017) <0.5m
			33.8					Lima *et al.*, 2020

2.7 Biogenic reefs

Biogenic reef habitats and their extent and nature in the Irish Sea and Welsh Coast Region are reviewed here. Although their value as blue carbon habitats is debated (as will be discussed), such habitats have considerable value in supporting ecosystem services and biodiversity.

2.7.1 Blue mussel (*Mytilus edulis*) beds

Background and UK context

Blue mussel beds occur naturally along shorelines where suitable substrata for attachment are found (Coolen *et al.,* 2020). Their habitat range extends from the high intertidal to the shallow subtidal zone, and from exposed rocky shores to sheltered bays, estuaries and sea lochs. The spatial extent, density and temporal persistence of blue mussel beds are highly variable, depending on local environmental conditions, but in some areas these beds can attain dimensions that justify their classification as biogenic reefs (Holt *et al.,* 1998). *Mytilus edulis* beds are composed of layers of living and dead mussels, with a matrix of accumulated sediment and shell debris bound together by networks of byssal threads. In the UK, beds rarely exceed 30–50 cm in thickness, but subtidal examples up to 120 cm thick have been reported (Holt *et al.,* 1998).

Mussels are capable of living for up to 18–24 years. However, the majority of mussels in beds are probably young, consisting of 2- to 3-year-old individuals, due to predation and the dislodgement of clumps of mussels by wave action and storms (Holt *et al.,* 1998). As mussel beds grow in size, individual mussels tend to become attached to other mussels rather than to the underlying substratum, so that large beds may be 'rolled up' and removed by wave action. Therefore mussel beds may vary in size and extent, and show a continuum between thin patchy beds and well-developed beds (Holt *et al.,* 1998). The bed extent and other characteristics may change over time, although beds in sheltered areas may develop and persist over longer timescales.

Blue mussels produce faeces and pseudofaeces which, together with silt, build up rich organic biodeposits under the beds. However, the longevity of these organic-rich biodeposits is likely to be limited as beds change and retract, and therefore they are unlikely to provide a long-term carbon store. *Mytilus edulis* was not included in the Scotland-wide assessment of blue carbon by Burrows *et al*. (2014) for this reason. Under optimal conditions *M. edulis* can reach a shell length of 60–80 mm within 2 years, but in the high intertidal zone the growth rate is significantly lower, and mussels may take 15–20 years to reach only 20–30 mm in length (Seed and Suchanek, 1992). Both biomass and carbonate production rate will therefore be heavily dependent on local conditions, and no single set of values can accurately represent all cases. Without detailed site-specific information (on bed thickness, mussel population size and structure and shell growth rate) it is not possible to assign values for specific beds (and thereby individual MPAs), and blue mussel beds are therefore treated as a 'data-deficient' category in this report. Stores and rates of production and sequestration of carbon have been assumed to be the same as those for *Modiolus* beds, in the absence of any relevant alternative information (see Table 4).

Irish Sea and Welsh Coast Region

Known blue mussel beds in the Irish Sea and Welsh Coast Region are shown in Figure 8. Both subtidal and intertidal beds are widespread throughout the region (12.4 km^2 of intertidal beds and 23.1 km^2 of subtidal beds; see Table 11). Extensive mussel beds are found along muddy shorelines from South Wales, along the Menai Straits and the southern fringes of Liverpool Bay, as well as further north around the coasts of Cumbria from Morecambe Bay to the southern edge of the Solway Firth.

2.7.2 Horse mussel (*Modiolus modiolus*) beds

Background and UK context

Biogenic carbonates are deposited by accumulated shells of the large bivalve *Modiolus modiolus*, and occur in living reefs as well as in areas that were previously occupied. *M. modiolus* is a long-lived, slow-growing bivalve with sporadic recruitment. Although horse mussels are responsible for large amounts of carbonate biomass, the annual IC productivity rates are relatively low, estimated to be 330 g $CaCO_3/m^2/yr$ (Collins, 1986). The largest UK bed was recorded in Scotland at Noss Head, but horse mussel beds are found throughout the UK. An average thickness of 75 cm in *M. modiolus* beds is used to calculate underlying carbonate stores (see Burrows *et al.,* 2017, 2021; Porter *et al.,* 2020). Field sampling in Scottish beds has provided an accurate estimate of calcium carbonate, which can be applied to English sites (Hirst *et al.,* 2012), but to our knowledge no such data are available for English sites. The area-specific storage density estimate adopted in this report is therefore 4,000 g IC/m^2.

Irish Sea and Welsh Coast Region

Only a single mapped *M. modiolus* bed (1.4 ha in area), located off the Lleyn Peninsula in North Wales, is present in the Natural England Marine Habitats and Species database; it is just visible in Figure 8. The habitat suitable for *M. modiolus* has been modelled in Strangford Lough in Northern Ireland (Strong *et al.*, 2016), showing a sharp decline from an area of 12.6 km^2 in 1986 to 5.4 km^2 in 2007. A recent review of blue carbon habitats and the potential for their restoration in Northern Ireland (Strong *et al.*, 2021) did not produce a value for carbon sequestration by horse mussel beds in the area.

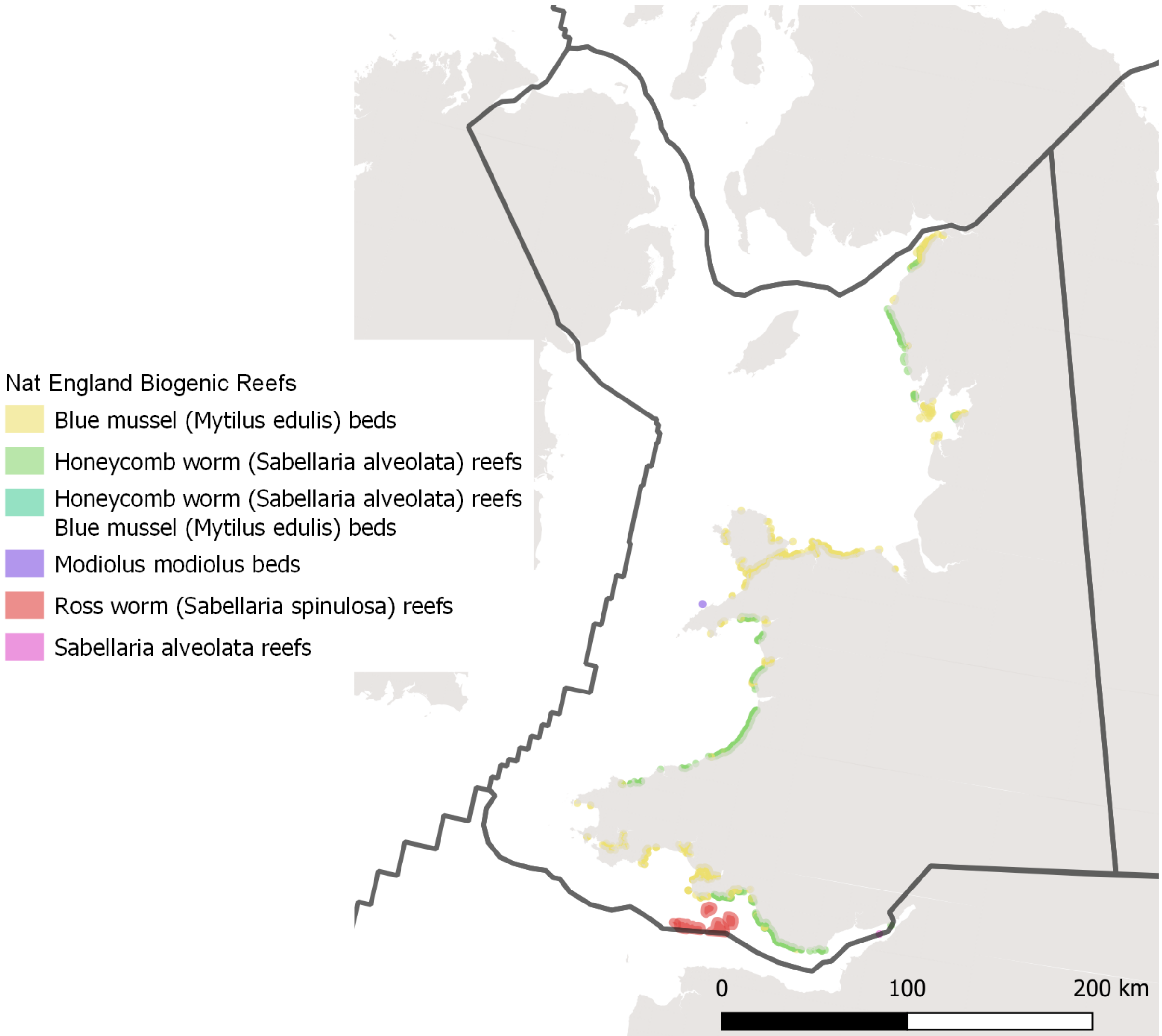


Figure 8. Subtidal and intertidal biogenic reefs from the Marine Habitats and Species GeoPackage shapefiles. These data are open source and available online (see Annex 1 for link). Reefs are shown with a 2-km buffer to enhance visibility at this scale. Only data from England and Wales are included.

2.7.3 Native oyster (*Ostrea edulis*) reefs

Background and UK context

Native oyster (*Ostrea edulis*) reefs are usually a net source of CO_2 due to carbonate formation (Fodrie *et al*., 2017), but shallow subtidal reefs and saltmarsh-fringing reefs (predominantly composed of oyster reefs present at the edge of a saltmarsh) are small net sinks (–1.0±0.4 t C/ha/yr and –1.3±0.4 t C/ha/yr, respectively) due to the presence of OC-rich sediments (Fodrie *et al*., 2017).

Irish Sea and Welsh Coast Region

Native oysters (*O. edulis*) are found throughout the Region (see, for example, the NBN Gateway), but are not recorded as reef-forming seabed habitats, and as such would not contribute significantly to blue carbon stores in the region.

2.7.4 Cold-water coral (*Desmophyllum pertusum*) reefs

Background and UK context

Cold-water corals (*Desmophyllum pertusum*, also known as *Lophelia pertusa*) typically support a range of other species by providing a three-dimensional structure that can be used both as shelter and as an attachment surface. The living coral framework and accumulations of relict calcareous material collectively represent an IC sink operating over a timescale of thousands of years, based on radiocarbon dating of coral fragments (Douarin *et al.,* 2013, 2014, cited in Burrows *et al.,* 2017). Although its localised occurrence means that the contribution of *D. pertusum* to total carbon storage is likely to be very small, simple calculations of coral mass per unit area based on the reported size of coral mounds (Burrows *et al.,* 2014) gave a store density estimate of 9,375 g/m^2. Rates of accumulation of *D. pertusum* mounds suggest a sequestration rate of IC of 35 g C/m^2/year (Burrows *et al.,* 2014), but releasing CO_2 in the process and thereby not directly mitigating CO_2-driven climate warming.

Cold-water coral reefs and coral gardens (artificially manipulated reefs) may also contribute to carbon sequestration by trapping sediment. Suspension- and filter-feeding macrofauna associated with coral branches intercept organic matter that would otherwise not settle on the seafloor and, through their action as ecosystem engineers, the increased turbulence generated by the coral framework and the depletion of organic matter in the boundary layer augment the influx to the coral community (Thurber *et al*., 2014).

The carbonate accumulation rates of Challenger Mound are lower than those of tropical shallow-water reefs (4–12% of the carbonate accumulation), but they exceed the carbonate accumulation rates of continental slopes by a factor of 3.9–11.8 (Titschack *et al*., 2009). White *et al*. (2012) found that cold-water coral reef ecosystems potentially turn over a significant proportion of the annual shelf carbon export in the Norwegian Sea, where reefs are abundant. However, carbon sequestration from this habitat is not currently considered to be significant in the UK (cited in Armstrong *et al*., 2012).

Irish Sea and Welsh Coast Region

Cold-water corals are not present anywhere in this Region.

2.7.5 *Sabellaria* reefs

Background and UK context

Sabellaria reefs are listed as a priority habitat under the UK Biodiversity Action Plan (BAP). The reefs are generally formed by two marine polychaete worms, *Sabellaria alveolata* and *Sabellaria spinulosa*, constructing tubes in tightly packed masses with a honeycomb-like appearance, which are 30–50 cm thick. By forming complex structures and reefs, both species provide a biogenic habitat which is often occupied by multiple associated species. Reef construction is not a calcification process, but rather one that binds and ‘cements’ sand particles to form complex three-dimensional structures (Franzitta *et al.,* 2022). Previous reports have therefore concluded that the blue carbon contribution from *Sabellaria* reefs is negligible, and have generally considered it to be the same as that from the surrounding sediments (Naylor and Viles, 2000; Burrows *et al*., 2021).

Irish Sea and Welsh Coast Region

Sabellaria alveolata reefs are widespread across the Irish Sea and Welsh Coast Region (Cunningham *et al.,* 1984; Curd *et al.,* 2020). Extensive reefs occur along the coasts of South Wales between the Gower Peninsula and Cardiff Bay, along the coastline of mid Wales around Aberaeron, south of Barmouth and Harlech, and along the west Cumbrian coast (see Figure 8). Such reefs are most often found on shores with mixed sediments of boulders, bedrock and sand, and can be up to 1–1.5 m high.

Figure 9. Sabellaria alveolata reefs at Tarn Bay. Photo taken on 23 July 2008 by M. Burrows.

2.7.6 Summary of parameters used for carbon contributions of biogenic reefs

Table 10. Production rates, sequestration rates and storage densities for common types of shallow-water biogenic reefs around the UK.[1] *Based on Burrows* et al. *(2021). Zero and missing values reflect absence of information.*

Biogenic reefs	**Production rate (g C/m²/yr)**		**Sequestration rate (g C/m²/yr)**		**Storage density (g C/m²)**	
	OC	**IC**	**OC**	**IC**	**OC**	**IC**
Modiolus modiolus	0	40	0	40	0	4,000
Mytilus edulis	0	40	0	40	0	15
Serpula vermicularis reefs	0	0	0	0	0	0
Sabellaria reefs	0	420	0	420	–	781
Brittlestars (shelf seas)	0	82	0	82	–	0
Subcanopy algae	21	0	0	0	22	0

[1] *Modiolus* beds are assumed to be 75 cm deep, *Mytilus* beds were assigned the same values as *Modiolus* beds. Sources of values and other assumptions are given in Burrows *et al.* (2017). Zero and missing values reflect unavailable data.

OC, organic carbon; IC, inorganic carbon.

Table 11. Extents and rates of carbon accumulation of biogenic reefs used for the Irish Sea and Welsh Coast Region assessment.

Irish Sea area (km²)	43112		Organic carbon			Inorganic carbon							
Habitat	Extent (km²)	Component area (km²)	Standing stock (1000 t)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Stock (1000t C)	Stock (g C/m²)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Refractory period	Source
Sublittoral biogenic reefs (A5.6)	19.37												Natural England Open Data
Sabellaria sp. reefs		6.97											
Modiolus modiolus		0.014						40					
Blue mussel (*Mytilus edulis*) beds		12.38					266	40					
Littoral biogenic reefs (A2.7)	33.99												Natural England Open Data
Blue mussel (*Mytilus edulis*) beds		23.05											
Honeycomb worm (*Sabellaria alveolata*) reefs		10.94											

Note [1]. Sabellaria reefs are assumed to have the same C content and storage as surrounding sediment

2.8 Sediments

2.8.1 Background and UK context

Seabed habitats develop through the prevailing hydrographic regime (tides, waves and residual currents) together with the underlying physiography and geology.Organic detritus and phytoplankton are incorporated into sediments via direct settlement and accumulation on the sediment (sedimentation), where labile and semi-labile dissolved and particulate matter is consumed by macrofauna and micro-organisms. The activities of benthic organisms promote the uptake of dissolved OC and suspended organic particles via bio-irrigation (flushing of sediments) and burrowing activities (bioturbation) that incorporate within the sediment organic matter that has been deposited at its surface (generally the top 10 cm). Respiration by the benthic community remineralises carbon as CO_2.

Where carbon is biologically inert (i.e., refractory) it may accumulate over timescales of thousands of years in deeper, less disturbed sediments (Aldridge *et al.*, 2017). Within offshore seabed sites in the Celtic Sea, POC is relatively uniform down to 25 cm, with a tendency to increase with depth due to decreasing porosity (Aldridge *et al.*, 2017). Some pools of OC may be historical and have accumulated over long time periods.

2.8.2 Irish Sea and Welsh Coast Region

Sediments in the Irish Sea and Welsh Coast Region (see Figure 10) consist of sands near the coasts of England and Wales, with coarse and mixed sediments towards the deeper parts of the Region, and a large area of mud to the south-west of Northern Ireland (the top of the Western Irish Sea Mud Belt) (Coughlan *et al.*, 2015). The most widespread sediment type in the Region is coarse substrate which is described as coarse sand, gravel, pebbles, shingle and cobbles. These substrates can be unstable when exposed to wave motion or tidal current action.

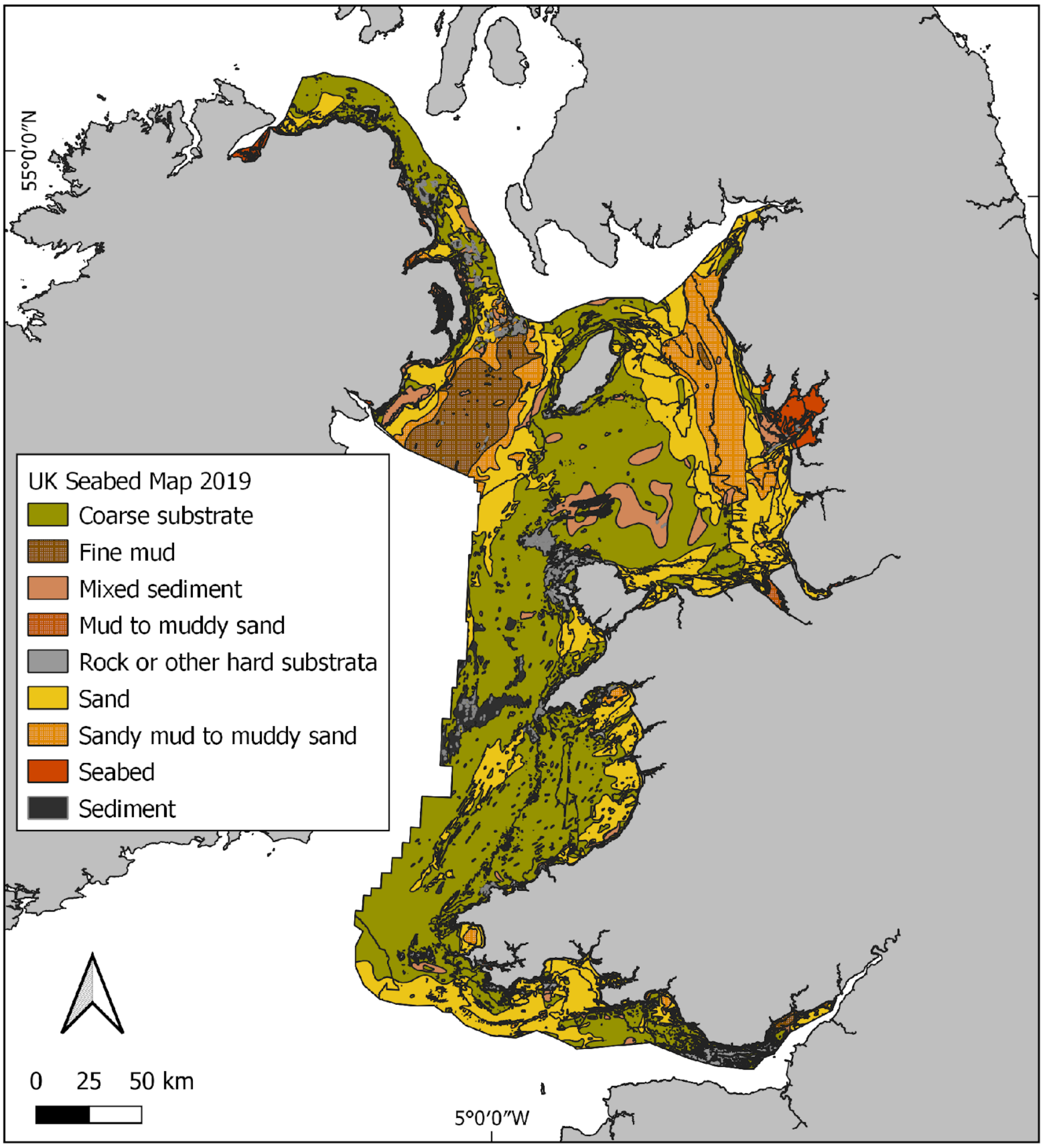


Figure 10. Seabed sediment descriptions from the EUSeaMap (2019). Unclassified seabed is included as 'Seabed' or 'Sediment'.

2.8.3 Carbon stores in seabed sediments

Analyses of the carbon content of historical BGS surface (top 10 cm) sediment grabs by Smeaton *et al.* (2021) have produced spatial maps of OC and IC across most of the UK's EEZ. For this Region these maps show considerable variation in OC density (see Figure 11 and Figure 12).

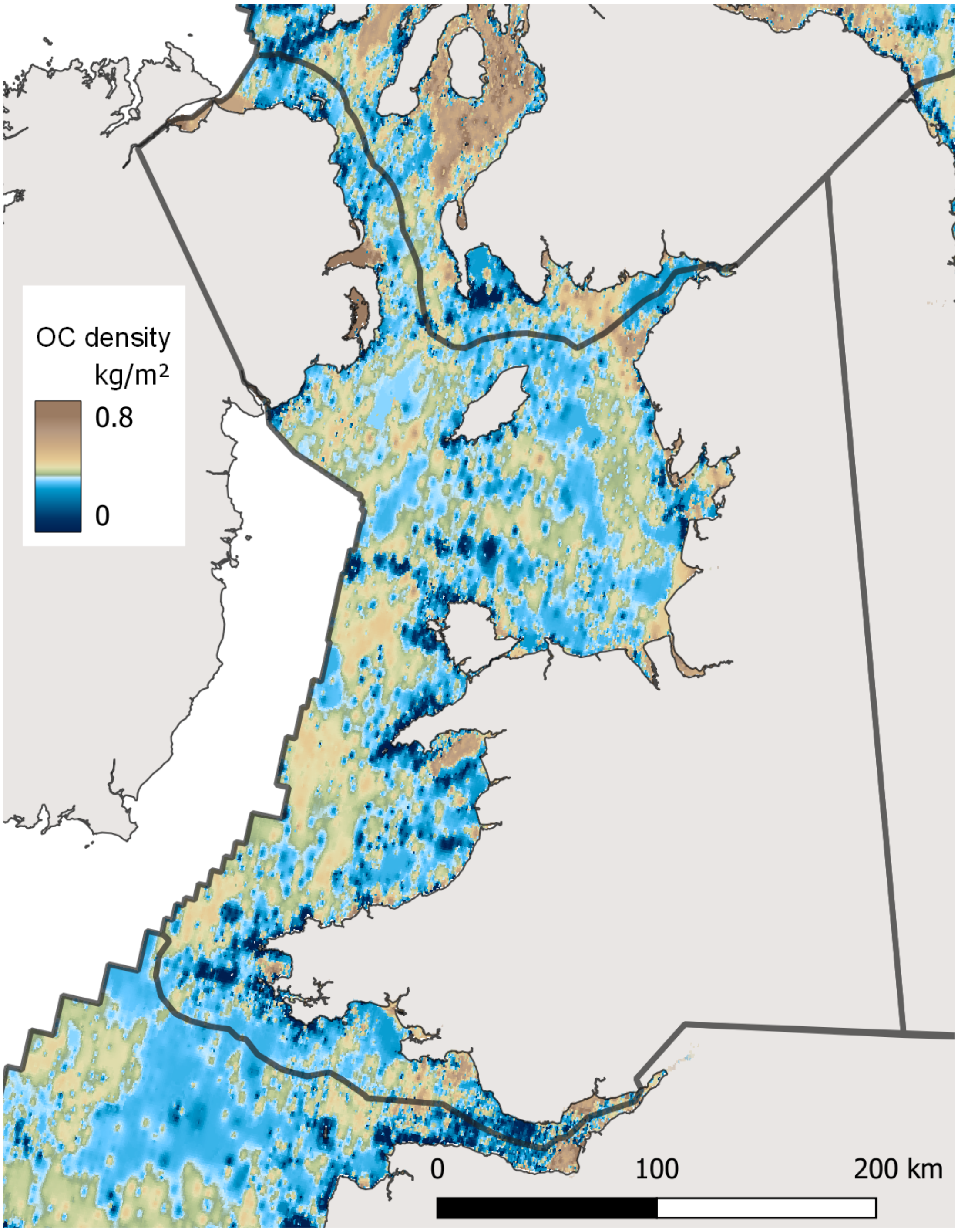


Figure 11. Organic carbon density in the top 10 cm of marine sediments in the Irish Sea and Welsh Coast Region. Data from Smeaton et al. *(2021).*

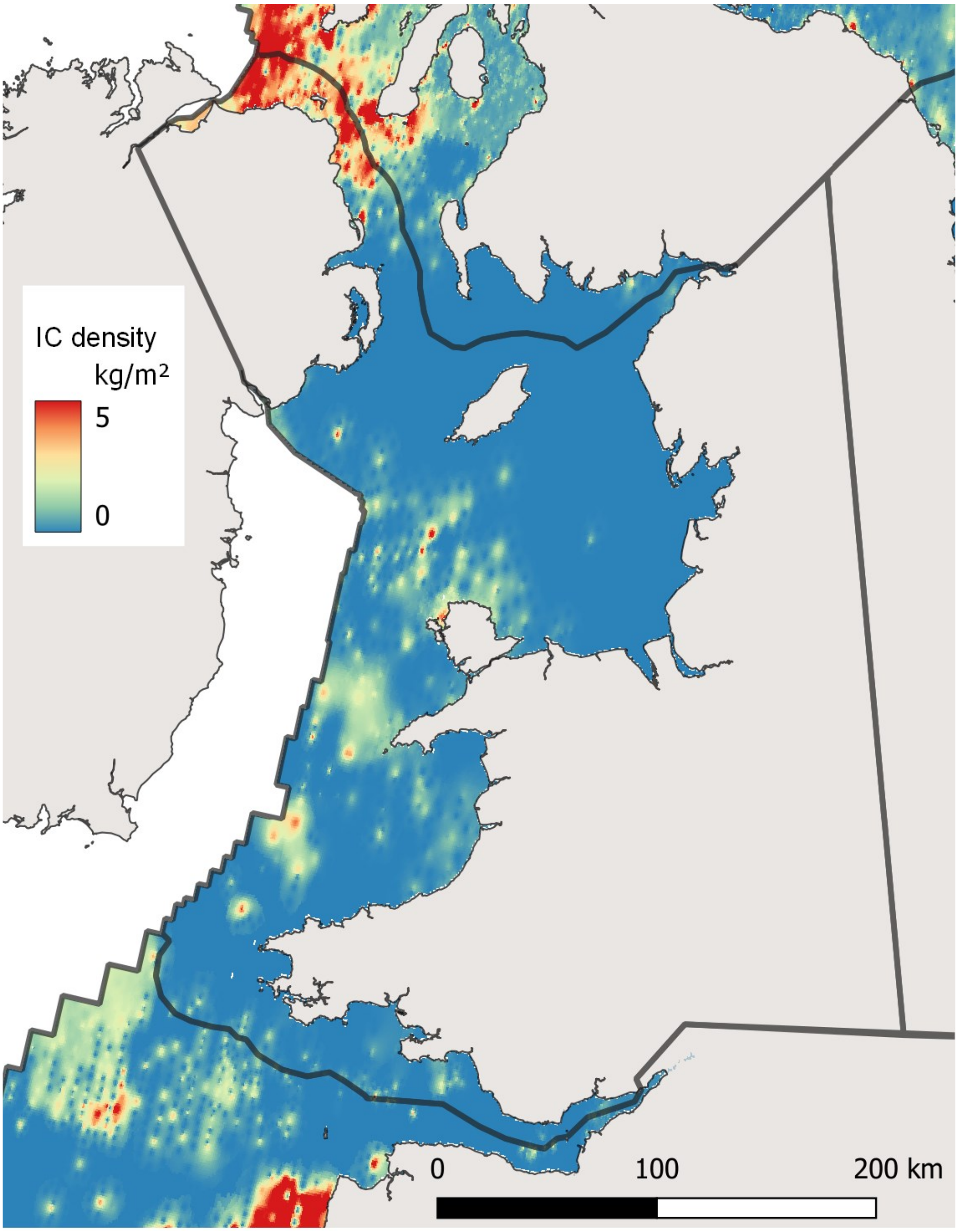


Figure 12. Inorganic carbon density in the top 10 cm of marine sediments in the Irish Sea and Welsh Coast Region. Data from Smeaton et al. *(2021).*

Sedimentation of POC transfers CO_2 from the atmosphere to the seabed, where it may be stored long term (from decades to centuries), mitigating increases in atmospheric CO_2 levels associated with climate change. Coarse sandy sediments allow water to flow freely through the upper parts of the sediment. This results in oxygen penetration allowing rapid carbon cycling and therefore low carbon storage in these sediments (Alonso *et al.,* 2012). Mud content and distance from the shore are factors that influence the OC content of sediments (Diesing *et al.,* 2017). Coarse sands do not have such high OC densities as inshore mud and vegetated habitats (see Table 12). Diesing *et al*. (2017) measured POC in UK shelf sediments. The highest POC concentrations are associated with gravelly mud, mud and sandy mud. Conversely, sands, gravel and sandy gravel exhibit the lowest POC concentrations. Offshore sands are much less likely to have high densities of OC than are inshore mud and vegetated habitats, but may support a larger store due to the greater extent of these habitats. Distance from the shore is also a factor influencing POC, due to the importance of terrestrial inputs. Particulate OC density (in kg/m^2) is higher in mud sediments (Diesing *et al.,* 2017), and mud content has been used as a proxy for OC storage by Hooper *et al*. (2017), based on referenced studies by de Falco *et al.* (2004), McBreen *et al.* (2008) and Serpetti *et al.* (2012).

2.8.4 Sediment thickness and carbon accumulation

Sediment data from the dataset presented in Figures 10–12 refer to the top 10 cm of sediment carbon only. The thickness of sediments in the seabed limits of the UK's EEZ can reach depths of over 12,300 m (12.3 km) according to some broad-scale, global datasets (Straume *et al.,* 2019) (see Figure 14). This dataset incorporates seismic refraction surveys from various studies which have estimated the basement layer (i.e., the basalt rock or solid layer) beneath accumulated layers of sediments. This layer can include soft silts, sand, clay and muds with highly variable carbon content, density and composition, and may have been deposited at any time from 2.6 million years ago to the present (LaRowe *et al.,* 2020). Therefore any estimate of the total carbon stored in sediment stores would have high levels of uncertainty, and for this reason such an estimate is not attempted here.

The main area of focus for sediment carbon content is described as the *bioturbated Holocene layer*, which generally incorporates the top 10 cm of the seabed and is likely to have been turned over and contributed to in recent times (Thomson *et al.,* 2000). The bioturbated Holocene layer can range from 10 cm to 300 cm (Coughlan *et al.,* 2019). It is this layer that is somewhat influenced by flows of organic matter. Beneath the bioturbated Holocene layer is the non-bioturbated Holocene layer, which again is thought to have been deposited during the most recent de-glaciation period, but deep enough to avoid bioturbation; it is therefore considered to be stable and only subject to change as it undergoes diagenesis (transformation of sediments to rocks over millennia).

The sediments in the Irish Sea and Welsh Coast Region are composed mostly of Quaternary deposits (i.e., dating from 2.6 million years ago to the present), and approximately 98% of the Region is thought to be covered by these deposits. Only small areas of the seafloor have exposed bedrock (Mellett *et al.,* 2015). Maximum depths of sediments in the area are reported to be over 50 m by Mellett *et al.* (2015), and 70–100 m thick by Coughlan *et al.* (2019), mainly in the western area of the Irish Sea and Welsh Coast Region, known as the Western Irish Sea Mud Belt (WISMB). However, the WISMB is not the thickest part of the Irish Sea sediments, and sediments in this Region are probably less than 100 m thick (see Figure 14). This is considerably less than the thickness of the other sediments in the UK (Funck *et al.,* 2017). These figures are consistent with the findings of Straume *et al*. (2019) for the Irish Sea and Welsh Coast Region, but it is worth noting that sediments may be much deeper in the southern part of the Irish Sea, reaching a thickness of over 9,000 m (see Figure 14). Sediment type can vary considerably with depth, but four distinct layers have been described by Coughlan *et al.* (2019), all having been deposited as the Irish Sea Ice Sheet retreated approximately 18,000 years ago. The youngest layer, Unit S1, which is present all over the seabed in the Region, contained up to 26.5 m of homogenous, clay-silt, fine-grained, dark olive-coloured sediments. These sediments are unconsolidated (i.e., loose or non-stratified, and particles that are not yet cemented together) and probably form both the bioturbated and non-bioturbated Holocene layers. To the east of the Isle of Man there is another muddy belt, named the Eastern Irish Sea Mud Belt. Here the thickness of the sediments is greater. Through the central part of the Irish Sea is coarse sediment which is continually exposed due to tidal currents in the area (see Figure 10 and Figure 13).

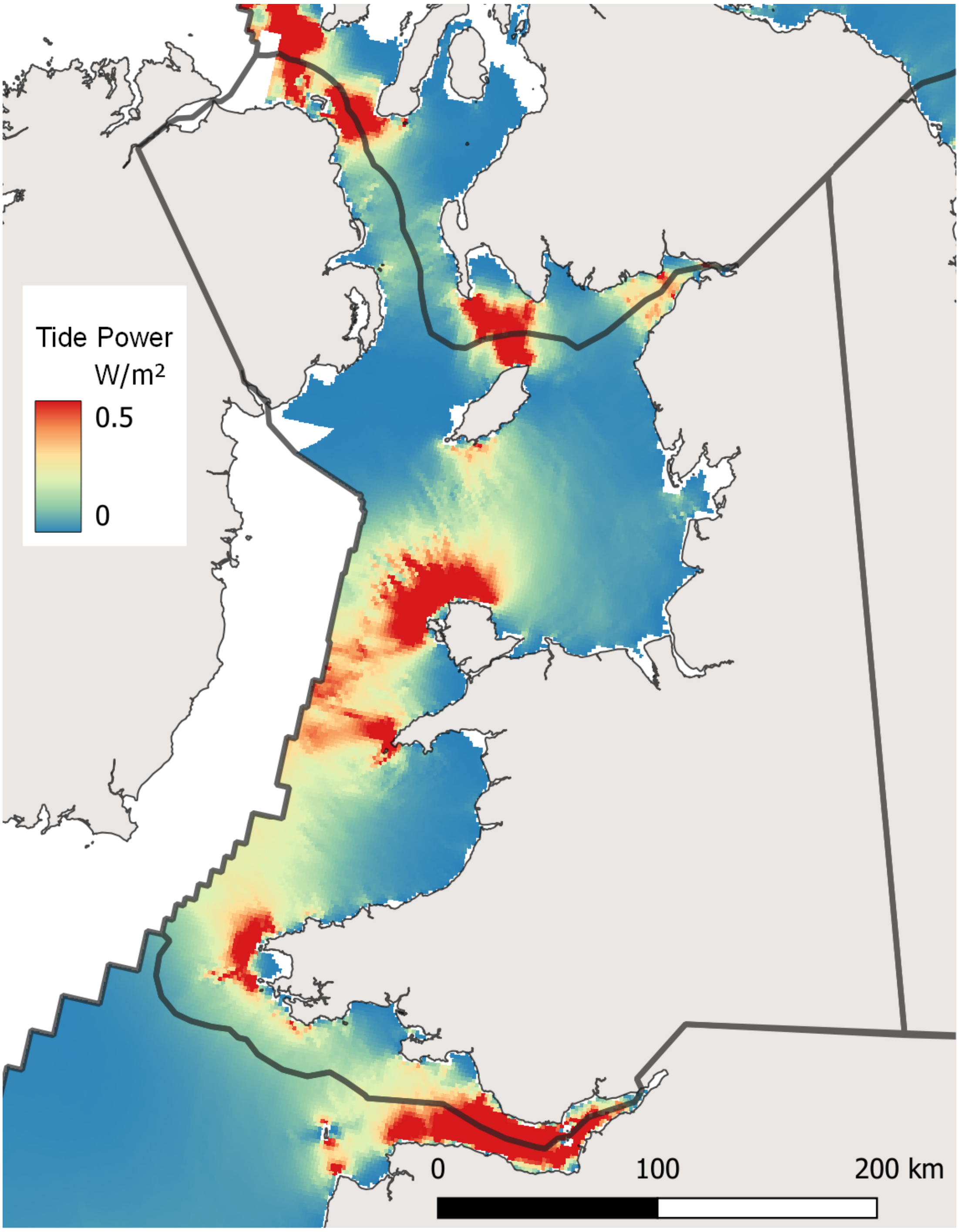


Figure 13. Tidal power in the Irish Sea and Welsh Coast Region. Data from the UK Atlas of Marine Renewables (a free resource hosted by ABPmer, 2022).

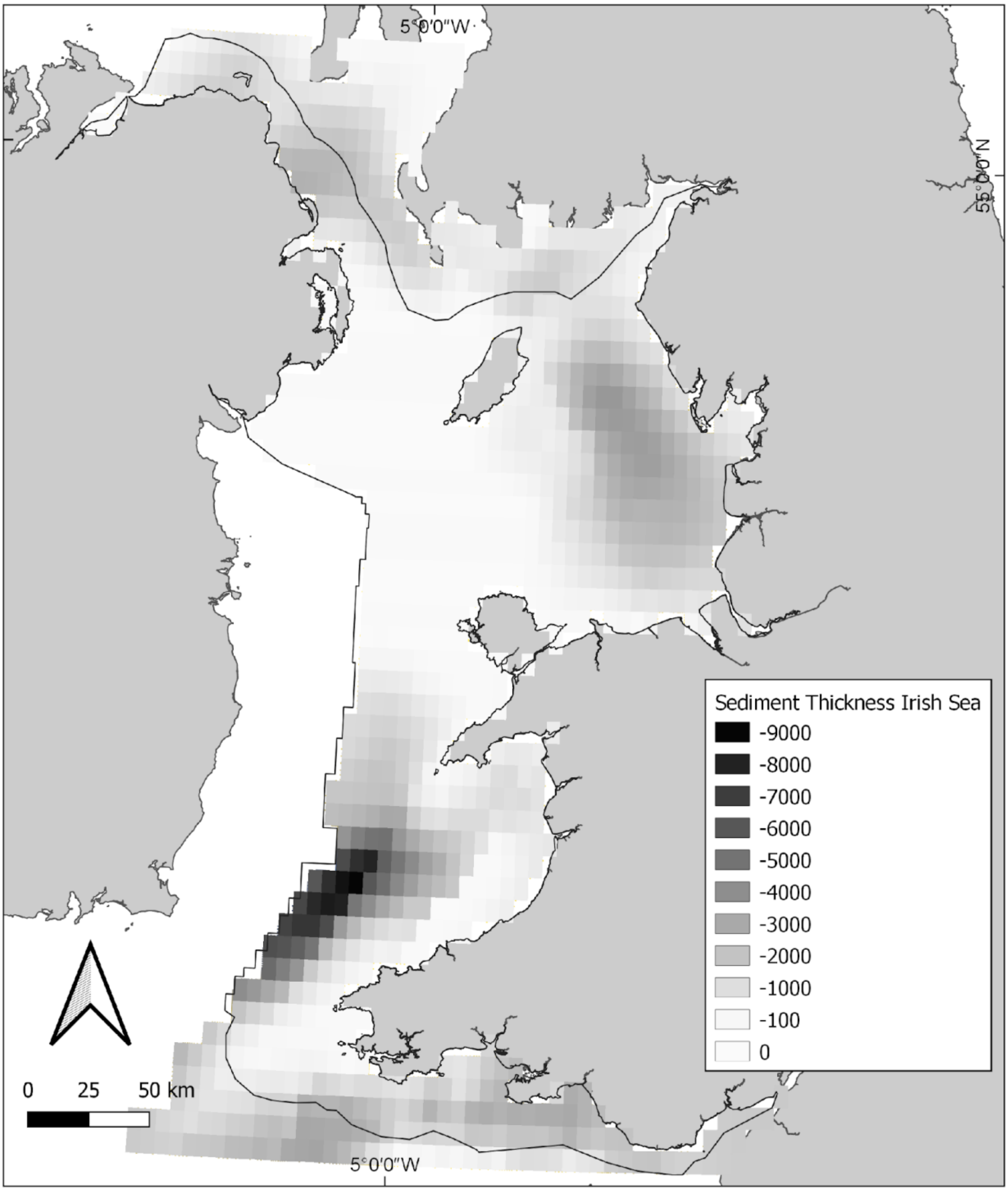


Figure 14. Sediment thickness estimated by seismic refraction from the surface of sediment layers to the mantle layer or the basement rock. The muddiest parts of the Irish Sea and Welsh Coast Region, to the north-east and west of the Isle of Man, are not necessarily the thickest sediments. Dataset clipped to the region; open source from Straume et al. *(2019).*

Table 12. Habitat- and area-specific estimates of organic carbon density and accumulation in marine sediments in the Irish Sea and Welsh Coast Region.

			Stocks													**Sequestration**				
			%OC		1m depth kgC/m²					0.1m depth gC/m²			**Sediment** cm/yr			**Carbon Accumulation** gC/m²/yr				
EUNIS code	Habitat	Sediment type	min	max	min	max	Avg	SD	n	min	max	Avg	min	max	Avg	min	max	Avg	Source	Comment
A1	Intertidal	Rock					0					0			0			0		Logical zero
A2.1	Intertidal	Coarse					0.0					0			0.000			0.0		
A2.2	Intertidal	Sand			1.3	18.6	6.5	4	4	130	1860	650			0.989			45.0	Duarte et al 2005	
A2.3	Intertidal	Mud			5.4	35.6	19.9	4	8	540	3560	1990	1.939	0.376	0.599	73.3	93.7	83.5	Adams et al., 2012; Potouroglou, 2017; Thornton et al., 2002; Trimmer et al., 1998	
A2.4	Intertidal	Mixed																42.8		
A2.5	Coastal saltmarshes and saline reedbeds																	129.0	CEH Land Cover Map; Habitat Review (Callaway et al 1996)	
A2.6	Intertidal/S	Seagrass beds																100.4	Habitat Review	
A2.7	Intertidal	Biogenic reef: mussel beds/Sabellaria					0.0					0			0.000			0.0		Not known
A2.8	Littoral	Rock					0					0			0			0.0		Logical zero
A3	Intertidal	Rock					0					0			0			0.0		Logical zero
A4	Circalittoral	Rock					0					0			0			0.0		Logical zero
A5	Sublittoral	All																0.2	De Haas et al 1997	
A5	Sublittoral	All	0.02	8.86															Habitat review	
A5	Sublittoral	All			0.6	6.1	2.6			64	608	264							Diesing et al 2017	min/max as 5%/95%iles
A5	Sublittoral	All			2.8	4.0	3.3			279	402	329							Smeaton et al 2021	min/max as 5%/95%iles
A5.1	Sublittoral	Coarse																		
A5.2	Sublittoral	Sand			0.4	7.6	1.8			40	760	180						0.2	Cefas data	
A5.2	Sublittoral	Sand	0.02	0.1	0.5	2.6	1.6			52	260	156				0.1	0.3	0.2	Burrows et al 2014	
A5.3	Sublittoral	Mud														0.2	2.7	1.1	Diesing et al 2021	
A5.3	Sublittoral	Mud	1.5	8	39.0	208.0	123.5			3900	20800	12350	0.068	0.200	0.180	18.7	291.6	155.2	Burrows et al 2014	
A5.3	Sublittoral	Mud			0.6	12.3	5.5			60	1230	550							Cefas data	
A5.4	Sublittoral	Sand/mud																59.0	Queiros et al 2019	English Channel L4: EUNIS A5.4 from NE habitats data
A5.4	Sublittoral	Sand/mud	1.5	4	39.0	104.0	71.5			3900	10400	7150	0.168	0.206	0.101	46.0	150.0	50.6	Burrows et al 2014	
A5.4	Sublittoral	Sand/mud														0.1	1.1	0.5	Diesing et al 2021	
A5.5	Sublittoral	Maerl																0.0		
A5.6	Sublittoral	Subtidal biogenic reefs: mussel beds																0.0		Not net carbon sequesterin
A6																				
A6.1	Deep	Rock					0					0			0			0.0		Logical zero
A6.2	Deep	mixed substrata																		
A6.3	Deep	Sand			3.9	17.8	10.9			390	1780	1085	0.001	0.002	0.002	0.0	0.2	0.1	Burrows et al 2014	Continental Slope
A6.4	Deep	Muddy sand																		
A6.5	Deep	Mud																		
	Oceanic	Continental shelf					35.6					3560							Atwood et al 2020	
		Other Coastal					6.3					630							Atwood et al 2020	
		Continental Slope					11.5					1150							Atwood et al 2020	
		Continental Slope			3.9	17.8	10.9			390	1780	1085	0.001	0.002	0.002	0.0	0.2	0.1	Burrows et al 2014	
		Abyss/Basin					7.6					760			0.000				Atwood et al 2020	
		Hadal					8.4					840			0.000				Atwood et al 2020	

Table 13. Habitat- and area-specific estimates of inorganic carbon density and accumulation in marine sediments in the Irish Sea and Welsh Coast Region.

			Stocks							Inorganic carbon Sequestration			
			%IC	0.1m depth kgC/m²			0.1m depth gC/m²			Accumulation rate gC/m²/yr			
EUNIS code	Habitat	Sediment type	Avg	min	max	Avg	min	max	Avg	min	max	Avg	Source
A1	Intertidal	Rock											
A2.1	Intertidal	Coarse											
A2.2	Intertidal	Sand											
A2.3	Intertidal	Mud											
A2.4	Intertidal	Mixed											
A2.5	Coastal saltmarshes and saline reedbeds												
A2.6	Intertidal/Su	Seagrass beds											
A2.7	Intertidal	Biogenic reef: mussel beds/Sabellaria											
A2.8	Littoral	Rock											
A3	Intertidal	Rock											
A4	Circalittoral	Rock											
A5	Sublittoral	All											
A5	Sublittoral	All											
A5	Sublittoral	All											
A5	Sublittoral	All	8%	0.04	1.697	0.55	44	1697	554	1.18	5.58	3.38	Smeaton et al 2021; Accumulation scaled as 10% Burrows et al 2014 estimates
A5.1	Sublittoral	Coarse											
A5.2	Sublittoral	Sand											
A5.2	Sublittoral	Sand	80%						26880	11.8	55.8		Burrows et al 2014
A5.3	Sublittoral	Mud											
A5.3	Sublittoral	Mud											
A5.4	Sublittoral	Sand/mud											
A5.4	Sublittoral	Sand/mud											
A5.5	Sublittoral	Maerl											
A5.6	Sublittoral	Subtidal biogenic reefs: mussel beds											
A6													
A6.1	Deep	Rock											
A6.2	Deep	mixed substrata											
A6.3	Deep	Sand											
A6.4	Deep	Muddy sand											
A6.5	Deep	Mud											
	Oceanic	Continental shelf											
		Other Coastal											
		Continental Slope											
		Continental Slope											
		Abyss/Basin											
		Hadal											

3 Carbon Stores and Accumulation Rates Across the Irish Sea and Welsh Coast Region and its Marine Protected Areas

As in the North Sea Region and the English Channel and Western Approaches Region, the MPAs in the Irish Sea and Welsh Coast Region were not designated for protection of carbon stores, but for biodiversity features. Here the quantities of carbon stored in sediments in MPAs within the Irish Sea and Welsh Coast Region are reviewed for the assessment of their conservation value and coverage by existing designations, and the identification of potential hotspots.

3.1 Carbon stores across the Irish Sea and Welsh Coast Region

The top 10 cm of marine sediments in the whole Irish Sea and Welsh Coast Region contain 14.7 Mt OC and 15.4 Mt IC (see Table 14).

3.2 Marine Protected Areas (MPAs)

Allowing for multiple designations, the total area covered by any kind of protected area in the Region is 43% of its total area. Without allowing for such overlapping designations, the 301 MPAs in the Irish Sea and Welsh Coast Region represent 72% of the total region, with MCZs accounting for 4%, SACs for 46%, SPAs for 18%, MNRs for 1%, and ASSIs and SSSIs for 3% of the total area of 43,000 km^2 (rounded up here to avoid spurious implied accuracy) (see Table 14 and Figure 13). The percentages of total OC stores falling inside MPAs broadly follow the percentages of the total area covered by MCZs, SACs, SPAs, MNRs and SSSIs. MCZs cover 5% of the region's OC stores (0.7 Mt OC), SACs cover 44% (6.4 Mt OC), SPAs cover 18% (2.6 Mt OC), MNRs cover 1% (0.1 Mt OC), and ASSIs and SSSIs cover 4% (0.6 Mt OC) of the total OC (14.7 Mt). Quantities of sediment IC in MPAs are such that MCZs cover 2% of total IC in the region (0.4 Mt IC), SACs cover 36% (5.5 Mt IC), SPAs cover 10% (1.6 Mt IC), MNRs cover 0% (no IC), and ASSIs and SSSIs cover 1% (0.2 Mt IC).

Table 14. Sediment carbon stores and accumulation rates in the Irish Sea and Welsh Coastal Region and its marine protected areas (MPAs). Carbon store density values were extracted from maps published by Smeaton et al. *(2021). Per-area organic carbon accumulation rates were derived from habitat reviews, and MPA totals were calculated as the product of these rates and MPA extents. Substrate was determined from the largest area of component habitat. Only ASSIs and SSSIs with an area of over 2 km^2 are listed. It should be noted that that areas may have multiple designations (e.g., Fylde MCZ overlaps with Liverpool Bay SPA), and that totals presented here include areas counted more than once.*

Name	Substrate	Area (km²)	OC density (kg/m²)	IC density (kg/m²)	OC store (1,000 t)	IC store (1,000 t)	OC accumulation (g C/m²/yr)	OC accumulation (kt yr^{-1})
Irish and Welsh Region		43,112	0.341	0.357	**14,720**	**15,371**	3.72	148.66
All MCZs		1,582	0.471	0.480	675	381	44.60	51.73
All MNRs		444	0.238	0.000	128	0	3.62	0.29
All SACs		19,985	0.336	0.632	6,407	5,487	26.81	276.94
All SPAs		7,908	0.304	0.193	2,584	1,573	25.29	101.76
All SSSIs		1259	0.493	0.238	567	153	45.46	55.83

Name	Substrate	Area (km²)	OC density (kg/m²)	IC density (kg/m²)	OC store (1,000 t)	IC store (1,000 t)	OC accumulation (g C/m²/yr)	OC accumulation (kt yr⁻¹)
Marine Conservation Zones (MCZs)								
West of Walney	Sediment	388	0.369	0.000	143	0	0.00	0.00
Fylde	Sediment	261	0.334	0.000	87	0	26.44	6.89
Strangford Lough	Sediment	165	1.110	0.000	183	0	61.84	0.70
West of Copeland	Sediment	158	0.307	0.000	48	0	0.20	0.00
Queenie Corner	Sediment	146	0.384	0.222	56	32	136.78	19.97
South Rigg	Sediment	140	0.352	0.000	49	0	107.90	15.10
Wyre-Lune	Sediment	92	0.389	0.000	36	0	52.62	4.60
Rathlin	Sediment	91	0.271	3.683	25	333	0.01	0.00
Solway Firth	Sediment	43	0.272	0.012	12	1	56.83	2.36
Allonby Bay	Sediment	39	0.291	0.282	11	11	3.00	0.12
Cumbria Coast – Zone 2	Sediment	22	0.307	0.000	7	0	27.15	0.38
Cumbria Coast – Zone 1	Sediment	18	0.305	0.000	6	0	27.89	0.33
Ribble Estuary	Sediment	15	0.567	0.000	9	0	74.97	0.94
Outer Belfast Lough	Sediment	3	0.705	0.000	2	0	137.91	0.35
Carlingford Lough	Sediment	1	1.216	0.483	2	1	0.00	0.00
Waterfoot	Sediment	1	0.353	2.991	0	2	0.00	0.00
Marine Nature Reserves (MNRs)								
West Coast	Sediment	185	0.309	0.000	57	0	0.56	0.09
Ramsey Bay	Sediment	97	0.310	0.000	30	0	1.55	0.13
Langness	Sediment	89	0.303	0.001	27	0	0.02	0.00
Calf and Wart Bank	Sediment	20	0.121	0.000	2	0	0.07	0.00
Skomer	Rock	13	0.174	0.000	2	0	1.45	0.00
Baie ny Carrickey	Sediment	11	0.159	0.000	2	0	0.00	0.00
Little Ness	Sediment	10	0.254	0.000	3	0	0.27	0.00
Niarbyl Bay	Sediment	6	0.231	0.000	1	0	0.00	0.00
Douglas Bay	Sediment	5	0.209	0.000	1	0	35.87	0.07
Port Erin Bay	Sediment	4	0.242	0.000	1	0	0.00	0.00
Laxey Bay	Sediment	4	0.310	0.000	1	0	0.00	0.00
Special Areas of Conservation (SACs)								
West Wales Marine/Gorllewin Cymru Forol	Sediment	7,376	0.312	0.243	2,298	1,789	3.66	12.87
North Anglesey Marine/Gogledd Môn Forol	Sediment	3,249	0.309	0.593	1,005	1,927	10.57	34.17
North Channel	Sediment	1,599	0.349	0.039	558	62	75.84	105.67
Pen Llyn a`r Sarnau/Lleyn Peninsula and the Sarnau	Sediment	1,461	0.298	0.294	435	430	19.92	25.10
Pembrokeshire Marine/Sir Benfro Forol	Sediment	1,380	0.246	0.031	339	42	4.17	1.85
Bristol Channel Approaches/Dynesfeydd Môr Hafren	Sediment	1,048	0.313	0.083	328	87	25.33	24.56
Cardigan Bay/Bae Ceredigion	Sediment	959	0.312	0.069	300	66	4.12	2.85
Carmarthen Bay and Estuaries/Bae Caerfyrddin ac Aberoedd	Sediment	661	0.329	0.101	218	67	8.22	4.89
Morecambe Bay	Sediment	616	0.402	0.000	248	0	48.90	27.79
Severn Estuary/Môr Hafren	Sediment	280	0.419	0.116	117	33	54.96	15.35
Y Fenai a Bae Conwy/Menai Strait and Conwy Bay	Sediment	265	0.341	0.272	91	72	16.41	4.31
Dee Estuary/Aber Dyfrdwy	Sediment	158	0.423	0.000	67	0	67.36	8.72
Strangford Lough	Sediment	154	1.202	0.000	185	0	93.76	0.70
Solway Firth	Sediment	151	0.291	0.173	44	26	32.19	4.83
Murlough	Sediment	119	0.309	0.110	37	13	0.17	0.00
Croker Carbonate Slabs	Rock	116	0.231	0.288	27	33	9.36	1.09

Name	Substrate	Area (km²)	OC density (kg/m²)	IC density (kg/m²)	OC store (1,000 t)	IC store (1,000 t)	OC accumulation (g C/m²/yr)	OC accumulation (kt yr⁻¹)
Skerries and Causeway	Sediment	109	0.304	4.991	33	542	0.11	0.01
Shell Flat and Lune Deep	Sediment	106	0.291	0.000	31	0	1.78	0.19
The Maidens	Sediment	75	0.268	1.706	20	127	0.17	0.01
Rathlin Island	Sediment	33	0.186	3.855	6	129	0.02	0.00
Limestone Coast of South West Wales/Arfordir Calchfaen de Orllewin Cymru	Rock	16	0.158	0.152	3	2	2.45	0.01
Drigg Coast	Sediment	14	0.367	0.000	5	0	59.64	0.57
Kenfig/Cynffig	Sediment	12	0.316	0.001	4	0	32.16	0.10
Glannau Môn: Cors heli/Anglesey Coast: Saltmarsh	Sediment	11	0.413	0.222	4	2	47.33	0.41
Red Bay	Sediment	10	0.328	3.734	3	36	0.00	0.00
Pisces Reef Complex	Sediment	9	0.346	0.000	3	0	103.76	0.91
Bae Cemlyn/Cemlyn Bay	Sediment	0	0.000	0.000	0	0	1.56	0.00
Special Protection Areas (SPAs)								
Liverpool Bay	Sediment	2,523	0.334	0.045	842	114	13.52	28.93
Skomer, Skokholm and the Seas off Pembrokeshire	Sediment	1,078	0.284	0.165	306	178	0.71	0.55
Anglesey Terns/Morwenoliaid Ynys Môn		1,018	0.291	0.689	296	701	4.19	4.16
Northern Cardigan Bay/Gogledd Bae Ceredigion	Sediment	827	0.326	0.222	270	183	23.53	15.16
Morecambe Bay and Duddon Estuary	Sediment	637	0.385	0.000	245	0	53.42	23.62
Solway Firth	Sediment	523	0.360	0.083	188	44	14.34	4.56
Glannau Aberdaron ac Ynys Enlli/Aberdaron Coast and Bardsey Island	Sediment	335	0.238	0.713	80	239	7.08	2.36
Bae Caerfyrddin/Carmarthen Bay	Sediment	335	0.298	0.102	100	34	1.59	0.50
Irish Sea Front	Sediment	180	0.332	0.303	60	55	0.62	0.11
The Dee Estuary	Sediment	116	0.415	0.000	48	0	65.75	6.57
Ribble and Alt Estuaries	Sediment	103	0.457	0.000	47	0	50.56	4.84
Severn Estuary	Sediment	64	0.445	0.136	28	9	61.59	3.91
Burry Inlet	Sediment	48	0.436	0.106	21	5	39.82	1.79
Mersey Estuary	Sediment	42	0.573	0.000	24	0	83.03	2.24
Traeth Lafan/Lavan Sands, Conway Bay	Sediment	27	0.447	0.291	12	8	42.36	1.14
Mersey Narrows and North Wirral Foreshore	Sediment	20	0.462	0.000	9	0	42.28	0.74
Grassholm	Sediment	17	0.038	0.000	1	0	0.00	0.00
Dyfi Estuary/Aber Dyfi	Sediment	13	0.454	0.332	6	4	51.93	0.54
Castlemartin Coast	Sediment	2	0.139	0.160	0	0	22.16	0.03
Ramsey and St David`s Peninsula Coast	Sediment	1	0.084	0.000	0	0	3.84	0.00
Glannau Ynys Gybi/Holy Island Coast	Sediment	0	0.006	0.718	0	0	4.87	0.00
Mynydd Cilan, Trwyn y Wylfa ac Ynysoedd Sant Tudwal	Sediment	0	0.271	0.210	0	0	17.63	0.01
Berwyn	Sediment	0	0.000	0.000	0	0	0.00	0.00
Ynys Seiriol/Puffin Island	Sediment	0	0.234	0.368	0	0	2.08	0.00
Sites and Areas of Special Scientific Interest (SSSIs and ASSIs)								
Morecambe Bay	Sediment	251	0.404	0.000	101	0	57.54	13.32

Name	Substrate	Area (km²)	OC density (kg/m²)	IC density (kg/m²)	OC store (1,000 t)	IC store (1,000 t)	OC accumulation (g C/m²/yr)	OC accumulation (kt yr⁻¹)
Upper Solway Flats & Marshes	Sediment	87	0.286	0.117	25	10	41.80	3.55
Ribble Estuary	Sediment	73	0.471	0.000	34	0	53.49	3.82
Lune Estuary	Sediment	71	0.360	0.000	25	0	57.89	3.77
Severn Estuary	Sediment	63	0.446	0.136	28	9	61.75	3.90
Dee Estuary/Aber Afon Dyfrdwy	Sediment	62	0.382	0.000	24	0	76.08	4.73
Mersey Estuary	Sediment	59	0.578	0.000	34	0	70.37	2.87
Duddon Estuary	Sediment	54	0.535	0.000	29	0	55.76	3.02
Dee Estuary	Sediment	50	0.455	0.000	23	0	53.34	1.83
Burry Inlet and Loughor Estuary	Sediment	44	0.450	0.094	20	4	40.25	1.62
Sefton Coast	Sediment	31	0.424	0.000	13	0	41.79	1.03
Arfordir Pen-bre/Pembrey Coast	Rock	31	0.463	0.150	14	5	40.04	1.17
Traeth Lafan	Sediment	27	0.447	0.291	12	8	42.33	1.13
South Walney and Piel Channel Flats	Sediment	21	0.536	0.000	11	0	76.95	1.27
North Wirral Foreshore	Sediment	20	0.460	0.000	9	0	42.52	0.74
Lough Foyle	Sediment	18	0.623	3.225	11	57	0.00	0.00
Milford Haven Waterway	Sediment	17	0.474	0.000	8	0	57.90	0.91
Strangford Lough Part 3	Sediment	17	1.309	0.000	22	0	150.62	0.10
Dyfi	Sediment	16	0.431	0.345	7	6	48.83	0.65
Strangford Lough Part 1	Sediment	15	1.437	0.000	21	0	0.00	0.00
Wyre Estuary	Sediment	14	0.488	0.000	7	0	63.02	0.84
Morfa Harlech	Sediment	14	0.444	0.018	6	0	47.15	0.57
Aber Taf/Taf Estuary	Sediment	13	0.515	0.097	7	1	36.81	0.44
Aber Afon Conwy	Sediment	13	0.312	0.148	4	2	41.11	0.42
Twyni Lacharn – Pentywyn/ Laugharne – Pendine Burrows	Sediment	11	0.359	0.064	4	1	39.33	0.40
Aber Mawddach/Mawddach Estuary	Sediment	10	0.447	0.166	4	2	48.53	0.36
Twyni Chwitffordd, Morfa Landimor a Bae Brychdwn/Whiteford Burrows, Landimore Marsh and Broughton Bay	Sediment	9	0.330	0.184	3	2	27.78	0.24
Newborough Warren – Ynys Llanddwyn	Sediment	9	0.415	0.220	4	2	43.79	0.35
Outer Ards	Rock	9	0.317	0.000	3	0	0.12	0.00
Drigg Coast	Sediment	8	0.364	0.000	3	0	48.62	0.38
Murlough	Sediment	8	0.303	0.097	2	1	0.00	0.00
Beddmanarch-Cymyran	Sediment	8	0.477	1.710	4	13	41.76	0.25
Carlingford Lough	Sediment	8	0.547	0.963	4	7	0.00	0.00
Afon Tywi	Rock	7	0.496	0.117	4	1	50.43	0.36
Strangford Lough Part 2	Sediment	5	0.852	0.000	4	0	65.48	0.01
Blackpill, Swansea	Sediment	5	0.349	0.269	2	1	39.53	0.18
Other ASSIs and SSSIs (187)		84	0.238	0.399	30	22	19.20	1.62

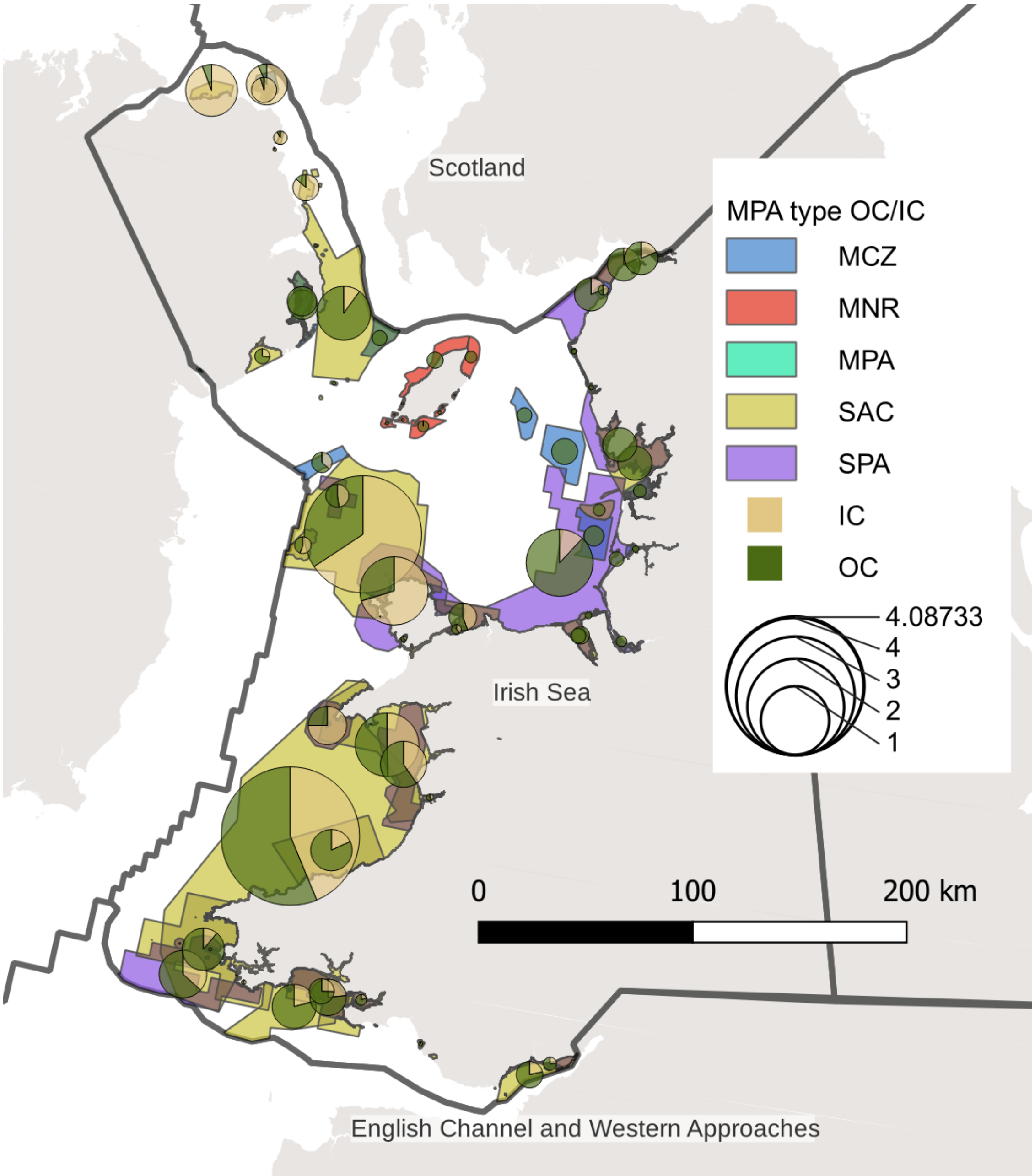


Figure 15. Marine protected areas in the Irish Sea and Welsh Coast Region, showing total organic carbon (OC) and inorganic carbon (IC) stores per marine protected area (data from Table 14).

3.2.1 Habitat extents within MPAs

The extents of habitats across the network of MPAs were derived using GIS processing to subset the whole Region habitat information (the Natural England Open Data habitat data layer) to the areas of the MPAs. Total areas of habitat types are shown in Table 1, and the size of associated carbon stores and the corresponding OC accumulation rates are shown in Table 14. More detailed information on habitat types is provided together with extents of designated features in Section 2, with reviews of the information available for each habitat in the Irish Sea and Welsh Coast Region.

3.2.2 Visualising patterns of stores and accumulation rates across MPAs

There are 301 MPAs in the Irish Sea and Welsh Coast Region (16 MCZs, 27 SACs, 24 SPAs, 11 MNRs and 223 ASSIs and SSSIs), each of which contains more than one habitat type, making simple comparisons among them based on inspection of tabulated data extremely difficult. Marine protected areas span habitats ranging from deep seabed to coastal rock and saltmarsh, with offshore MPAs covering larger areas, and shallow and intertidal (circalittoral) MPAs being generally smaller. However, the patterns of carbon storage among these varied and widely different MPAs can be visualised using ordination techniques known as non-metric multidimensional scaling (MDS) (see Figure 16), based on the composition of habitats within each MPA boundary. The ordination analysis separated small, shallow coastal areas on the left of the MDS plots from large, deep offshore areas on the right of the plots. Marine protected areas composed of rocky and coarse sediment habitats were placed at the bottom of the plots, while those composed predominantly of mud seabed were placed towards the top, with those composed of sand and coarse sediment placed halfway up. Offshore ('sublittoral') MPAs (see Figure 16a) tend to be much larger than inshore ('littoral) ones, with the largest of these composed mostly of sand and coarse sediment (see Figure 16b).

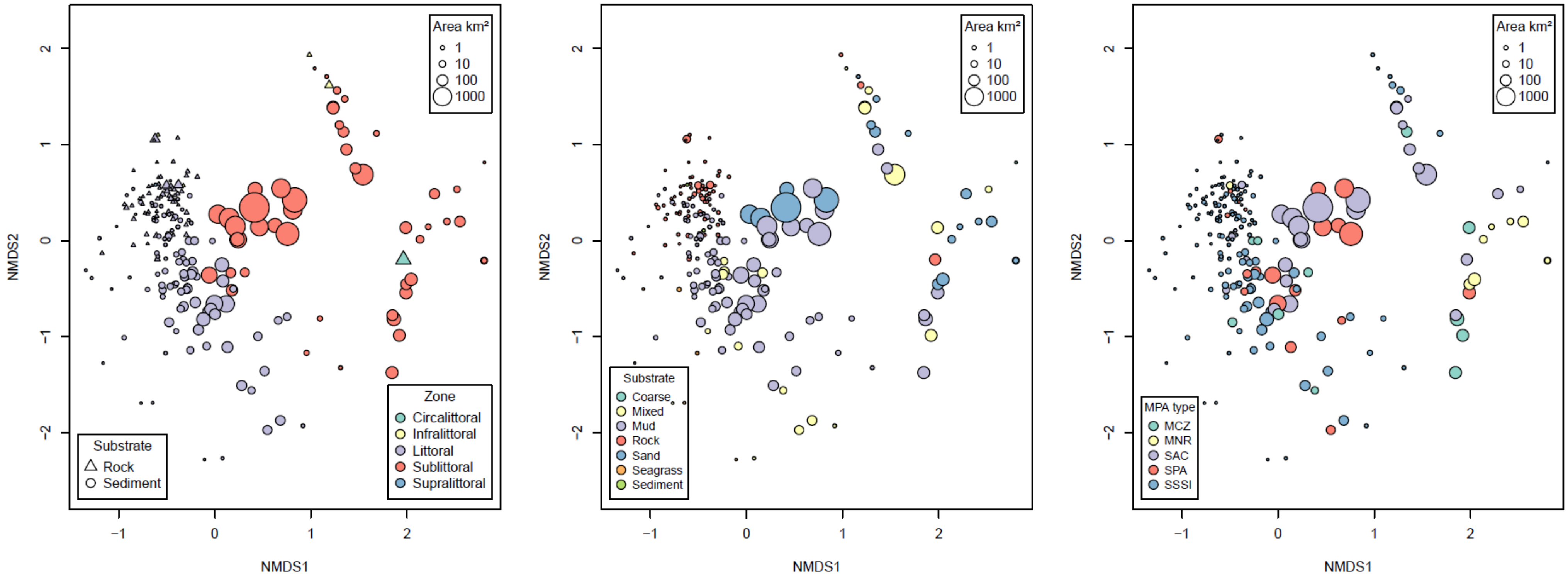
3.2.3 Carbon stores in the Irish Sea and Welsh Coast Region's MPAs

The amount of carbon in short- and long-term stores in each MPA (see Table 14) depends on the kinds of habitat present. Using the Natural England GIS data for seabed habitats across the Region (see Table 1), the extent of each habitat type present in each MPA was estimated. Although the resolution of the habitat information often exceeded the resolution of the available sediment carbon data (see Figure 11), the mix of habitats and dominant habitat by area were good indicators of the value of the MPAs in terms of OC density (see Figure 17) and total OC store. Small inshore MPAs, mostly SSSIs (see Figure 17c), had the highest OC density values (see Figure 17a), and were composed mainly of mud habitats (see Figure 17b). Marine protected areas with predominantly rocky habitats had unexpectedly significant OC density values from the matching of the interpolated point sampling of OC in sediments to the seabed habitat map information. This was probably due to the proximity of OC-rich coastal mud habitats to rocky areas, as is seen in other locations, such as Scottish sea lochs.

Despite the variation in OC density across the MPAs, with a tendency towards higher OC density in shallow coastal muddy areas, the total OC store was much larger in the more extensive offshore MPAs, particularly those MCZs and SACs that contained sand and coarse sediment (see Figure 18).

3.2.4 Rates of carbon accumulation across the Irish Sea and Welsh Coast Region's MPAs

Estimated area-specific rates of OC accumulation in sediments, using habitat-specific accumulation rates from Table 14 and summed across the within-MPA habitat extents to give the values shown in Table 14, can also be visualised in this framework. The MPAs with high OC density tended to be those with the highest estimated carbon accumulation rate (Pearson's correlation coefficient $r = 0.49$, $n = 227$; compare Figure 17 with Figure 19). This association was expected, since the latter measure was driven strongly by the presence of rapidly accumulating mud habitats in each MPA.



(a) (b) (c)

Figure 16. Ordination of the area-based composition of habitat types across the Irish Sea and Welsh Coast Region MPAs using non-metric multidimensional scaling. Each symbol represents a single MCZ, MNR, SAC, SPA or ASSI/SSSI, with the size of the symbol indicating the area of each MPA: (a) the type of symbol denotes the seabed type, and the colour denotes the depth zone; (b) the colour denotes the substrate type; (c) the colour denotes the type of MPA. Substrate and zone types in (a) and (b) are taken from EUNIS 2012 habitat descriptions.

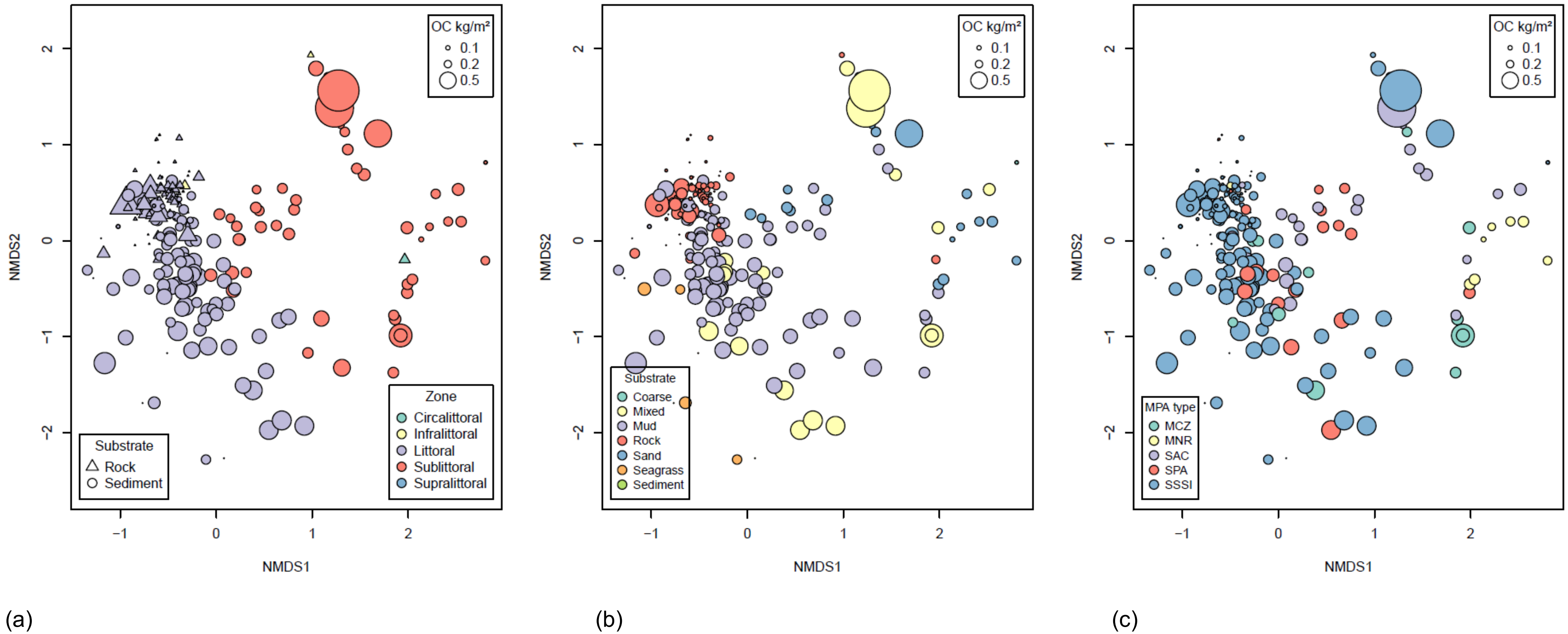
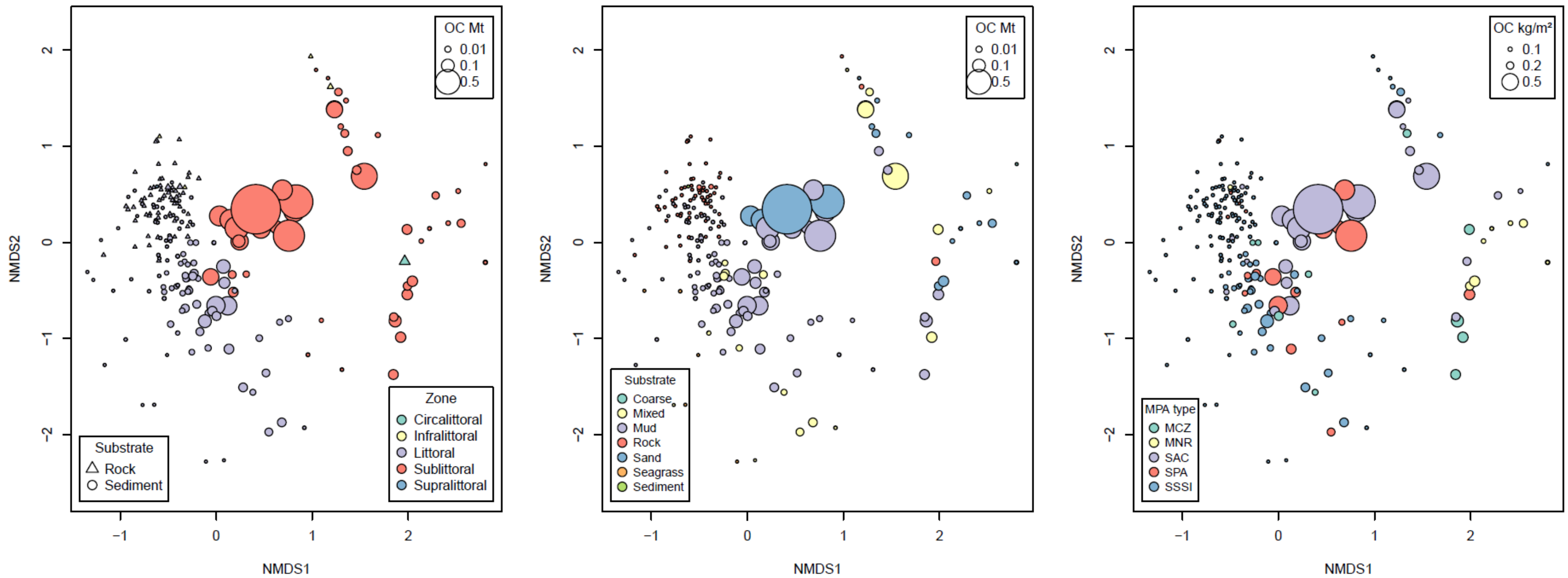
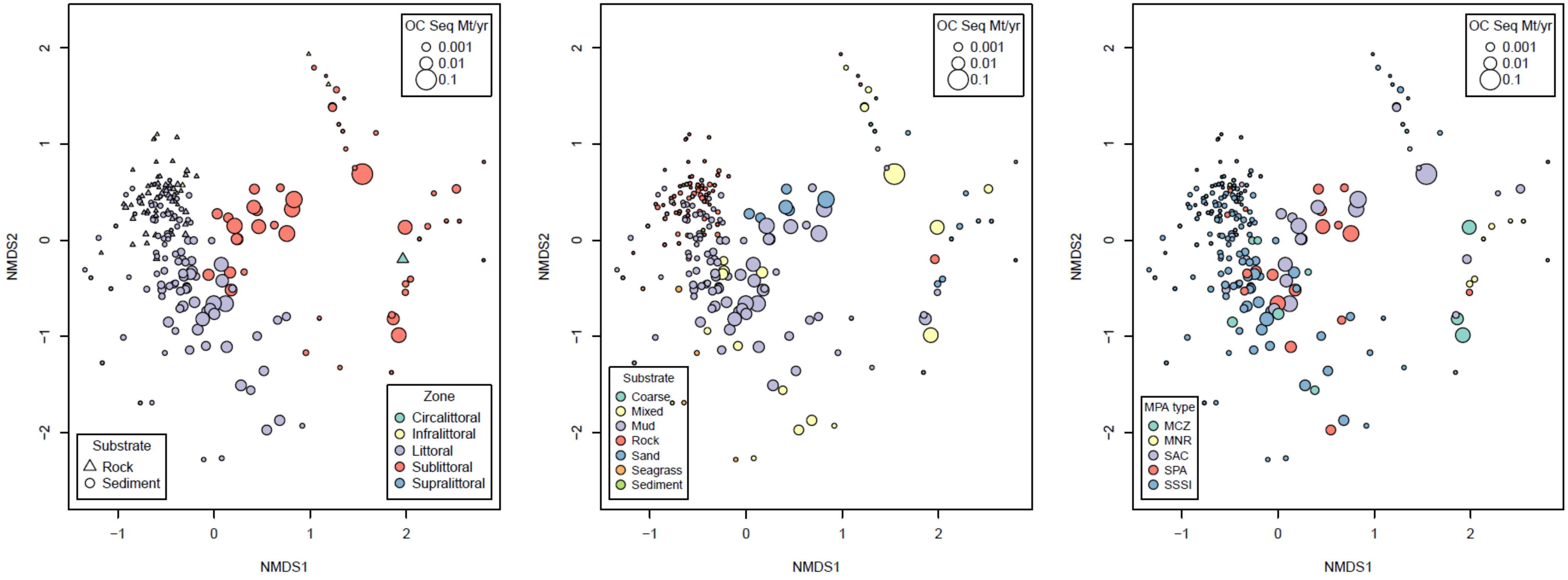


Figure 17. Ordination of the area-based composition of habitat types across the Irish Sea and Welsh Coast Region MPAs using non-metric multidimensional scaling. Each symbol represents a single MCZ, MNR, SAC, SPA or SSSI, with the size of the symbol representing the average organic carbon (OC) content (in kg/m^2) in the top 10 cm of sediment: (a) the type of symbol denotes the seabed type, and the colour denotes the depth zone; (b) the colour denotes the substrate type; (c) the colour denotes the MPA type. Substrate and zone types in (a) and (b) are taken from EUNIS 2012 habitat descriptions.



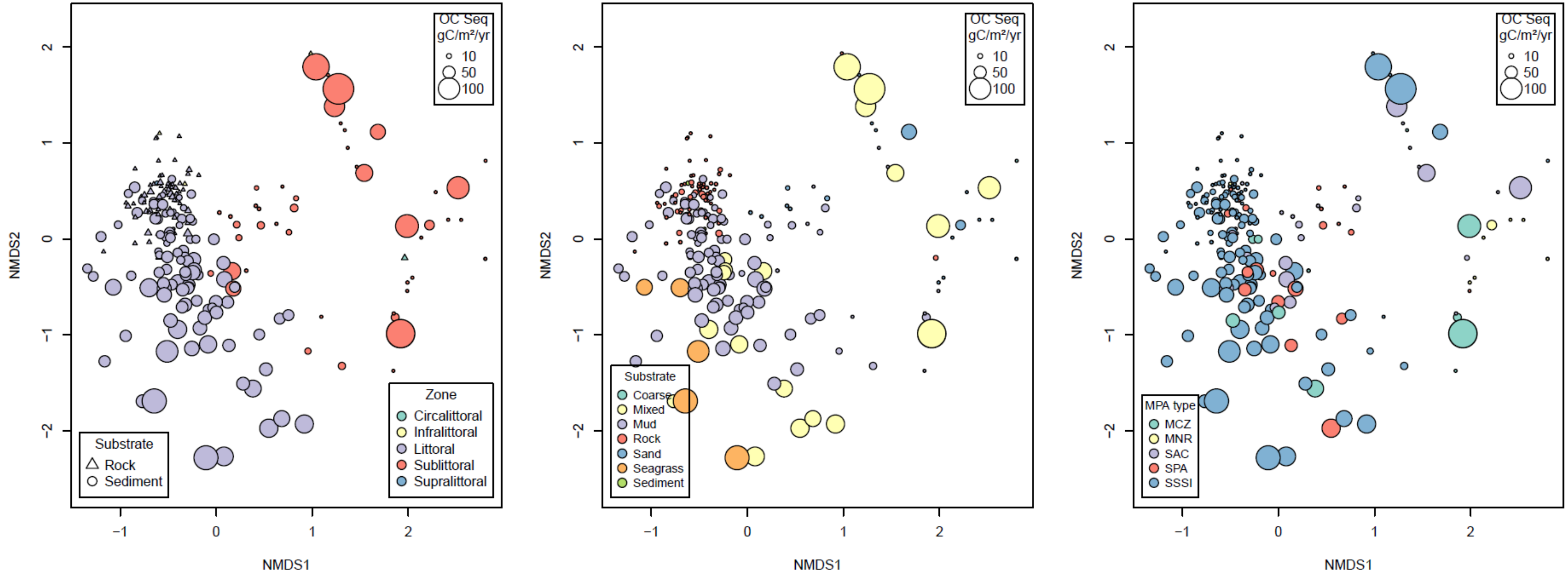
(a) (b) (c)

Figure 18. Ordination of the area-based composition of habitat types across the Irish Sea and Welsh Coast Region MPAs using non-metric multidimensional scaling. Each symbol represents a single MCZ, MNR, SAC, SPA or ASSI/SSSI, with the size of the symbol representing the total organic carbon (OC) content (in Mt) in the top 10 cm of sediment: (a) the type of symbol denotes the seabed type, and the colour denotes the depth zone; (b) the colour denotes the substrate type; (c) the colour denotes the MPA type.



(a) (b) (c)

Figure 19. Ordination of the area-based composition of habitat types across the Irish Sea and Welsh Coast Region MPAs using non-metric multidimensional scaling. Each symbol represents a single MCZ, MNR, SAC, SPA or SSSI, with the size of the symbol representing the total sediment organic carbon (OC) accumulation rate (in Mt/yr): (a) the type of symbol denotes the seabed type, and the colour denotes the depth zone; (b) the colour denotes the substrate type; (c) the colour denotes the MPA type.



(a) (b) (c)

Figure 20. Ordination of the area-based composition of habitat types across the Irish Sea and Welsh Coast Region MPAs using non-metric multidimensional scaling. Each symbol represents a single MCZ, MNR, SAC, SPA or SSSI, with the size of the symbol representing the total sediment organic carbon (OC) accumulation rate (in g C/m^2/yr): (a) the type of symbol denotes the seabed type, and the colour denotes the depth zone; (b) the colour denotes the substrate type; (c) the colour denotes the MPA type.

3.3 Ecosystem-scale carbon budget

Summarising the dynamics of carbon stores across the main blue carbon habitats and their associated sediment stores (see Table 15) shows the relative importance of each component. Although some elements remain unknown, these values show the overriding importance of phytoplankton and sublittoral sediments as the primary carbon source and carbon store, respectively, in the Irish Sea and Welsh Coast Region.

Table 15. Summary of carbon stores and sequestration capacity in the Irish Sea and Welsh Coast Region. The values shown summarise the carbon store and extent estimates presented in the habitat reviews (see Sections 2.1–2.6), and the description of sediment carbon stores (see Section 2.7). Grey background indicates that either no data are available or there is insufficient evidence to present values with confidence. The lower part of the table lists contributions by blue carbon habitats. Method 1 is described in Section 2.7.3 (see also Burrows et al.*, 2021).*

Irish Sea and Welsh Coast 2023		***Organic carbon***								***Inorganic carbon***					
Habitat	Extent (km²)	Organic carbon total (Mt C) [0.1m depth]	Organic carbon density (g C/m²)	Production rate (g C/m²/yr)	Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Stock (Mt C) [0.1m depth]	Stock (kg C/m²) [0.1m depth]	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)
Phytoplankton	43112			81	3508	351									
All sediment (Method 1)	43112	14.7	341				1145	30.2	1145	15.4	0.4	3.4	131		
Biogenic habitats	1800	1.2		307	552	55	119		123						
Total / Average	44912	15.9		90	4060	406	1264		1268	15.4			131		
Long-term stores		15.7													

		Organic carbon								***Inorganic carbon***					
Habitat	Extent (km²)	Organic carbon total (Mt C) [0.1m depth]	Organic carbon density (g C/m²)	Production rate (g C/m²/yr)	Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Stock (1000t C)	Stock (kg C/m²)	Storage rate (g C/m²/yr)	Storage capacity (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)
Vegetated habitats															
Kelp beds	1477.4	204.0	138	332	490.8	49.1		0	0						
Intertidal macroalgae	65.8	8.8	122	378	24.9	2.5		0	0						
Seagrass beds	26.0	62.1	2390	274	7.1	0.7	1.9	100.4	2.6						
Saltmarshes	213.4	932.1	4085	138	29.5	2.9	117.3	129.0	120.2						
Biogenic reefs															
Modiolus modiolus beds	0.0														
Sabellaria reefs	17.9														
Total	1800.5	1207.1		307	552.2	55.2	119.2	16.7	122.9						
Long-term stores		994.3													

3.3.1 Organic carbon (OC)

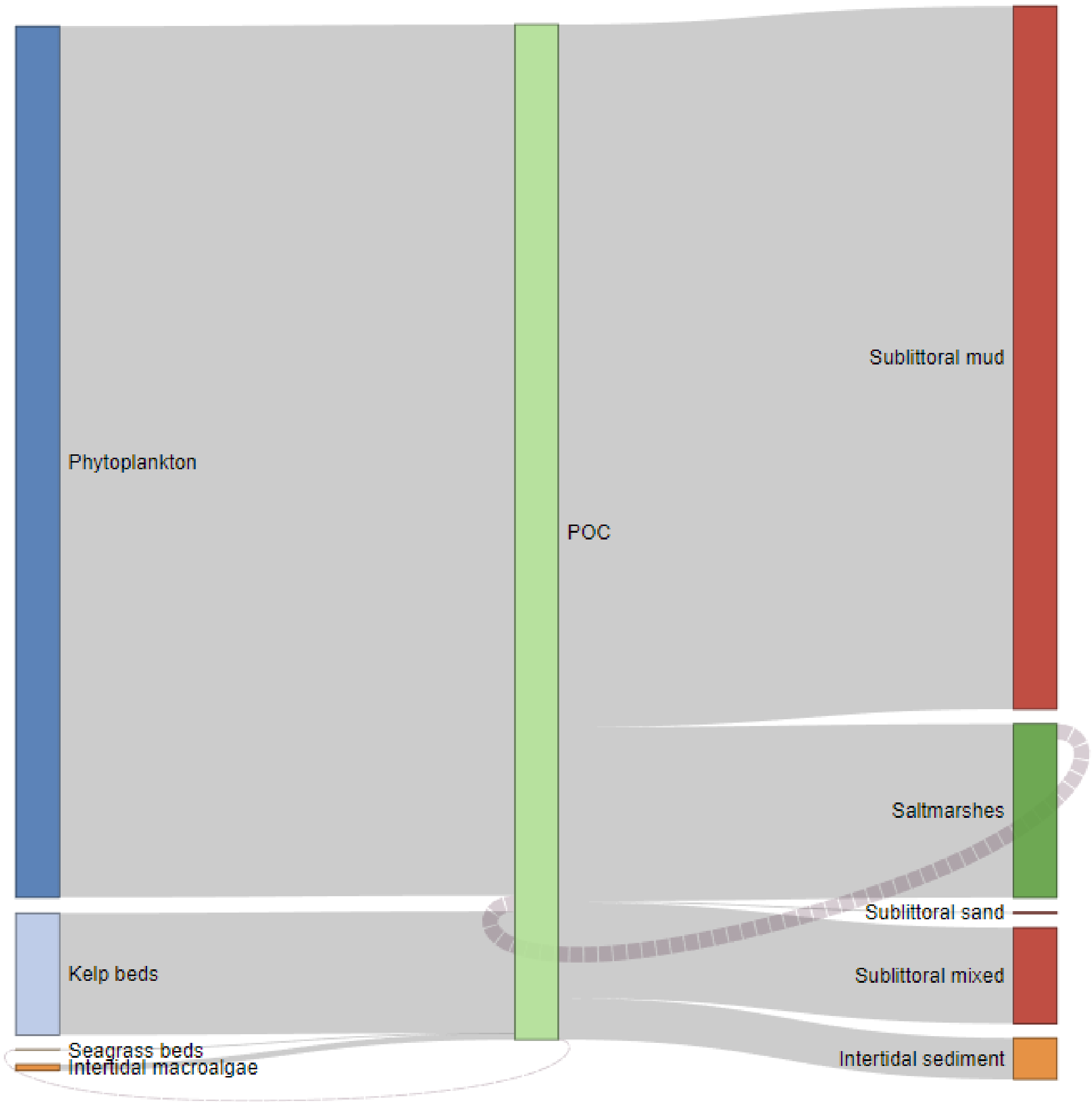


Figure 21. Annual flows of organic carbon from sources to stores in the Irish Sea and Welsh Coast Region, based on values presented in Table 15, and shown as a Sankey diagram with flows from left to right. The heights of each block represent the flows into and out of each carbon source or sink, with the sum of particulate organic carbon (POC) that reaches the seabed produced annually from phytoplankton (green central bar) estimated to be 351,000 t C (0.35 Mt C/yr) for reference. Total inputs of POC to stores (1.26 Mt C/yr) have been scaled to match estimated total outputs from primary producers (0.41 Mt C/yr).

Flows of OC from sources to stores (see Figure 21) show the dominant contribution of phytoplankton over coastal vegetated habitats (blue carbon in the original sense). Elsewhere it has been assumed that 10% or less of the annual production of organic material as plant growth and reproduction is exported as POC. Given this percentage and the estimated total production from phytoplankton in the Region using values reported in the literature (81 g C/m^2/yr), a total of 0.35 Mt C may be added to the POC pool each year by phytoplankton.

Annual plant growth and losses in blue carbon habitats contribute 55,000 t C to POC, with kelp beds contributing potentially most of this POC (49,000 t C), followed by saltmarshes (2,900 t C), intertidal macroalgae (2,500 t C) and seagrasses (700 t C). The annual export of POC from blue carbon habitats is 10% of the combined total exported by phytoplankton and blue carbon habitats.

The accumulation of OC in blue carbon habitats and sediment stores is estimated independently of estimated exports of POC, being largely calculated from sediment accumulation rates. Unlike the North Sea Region and the English Channel and Western Approaches Region (Burrows *et al*., 2021, 2024a), the total estimated import of OC to sediment stores in the Irish Sea and Welsh Coast Region, based on habitat-specific carbon accumulation rates (1.26 Mt C/yr; see Table 15, Influx), is much greater than the estimated total exports of OC from primary producers (phytoplankton and coastal vegetation export 0.41 Mt C/yr as detritus to the POC pool; see Table 15, Outflux). This imbalance suggests that imports of OC to sediments from outside the Region's marine habitats may be particularly important. Blue carbon habitats, particularly saltmarshes, accumulate OC at a faster rate than offshore sediments.

3.3.2 Inorganic carbon (IC)

Inclusion of IC in an audit such as this can be misleading, since the overriding consideration must be that the calcification process that produces the shell material which forms the bulk of this carbon store releases CO_2, and therefore cannot contribute positively to a greenhouse gas inventory (Frankignoulle *et al*., 1994). However, information on the extent of the IC stores and their dynamics remains important, since the dissolution of already formed calcium carbonate material can increase alkalinity, absorbing dissolved CO_2 and countering ocean acidification.

4 Case Study: The Isle of Man Territorial Seas

4.1 Introduction

The Isle of Man has been a self-governing Dependency under the possession of the British Crown since 1828. The marine boundary of the territorial waters surrounding the Isle of Man shares its borders with the territorial waters of Wales to the south, Scotland to the north, Northern Ireland to the west and England to the east. The coastline of the Isle of Man is approximately 160 km in length. As a self-governing body, the Isle of Man has control of the legislation and management of its territorial waters, which extend out to a maximum of 3 nautical miles (NM), from its coastline, and shared rights out to 12 NM from its coastline. The territorial waters cover a total area of around 4,000 km^2 (see Figure 22).

The Isle of Man Parliament (Tynwald) recognised the global climate emergency in 2019, and in 2021 the Climate Change Act (2021) came into effect. In 2022 the statutory Isle of Man Climate Change Plan (2022–2027) was introduced (the Isle of Man Government Action Plan for Achieving Net Zero Emissions by 2050). The plan contains missions for the Isle of Man to reach net zero by 2050, including agricultural, land and sea deliverables to meet these targets. Even though the carbon sequestered by blue carbon ecosystems is not viewed as a 'silver bullet' solution, the Manx government states that understanding the extent and distribution of blue carbon ecosystems plays a role in forming a holistic response to the climate and nature emergency.

The Isle of Man has 10 MNRs which are designated for the preservation of multiple marine features (discussed in Section 4.4). In addition to MNRs, the Isle of Man has a region of the coastline protected as National Nature Reserve (NNR). The Ayres NNR is an area of coastline designated to protect an extensive lichen heath and several breeding bird species. There are several regions along the coast also designated as ASSIs, in Castletown, parts of Baie ny Carrickey and regions to the south of Douglas, to protect certain habitats and bird life.

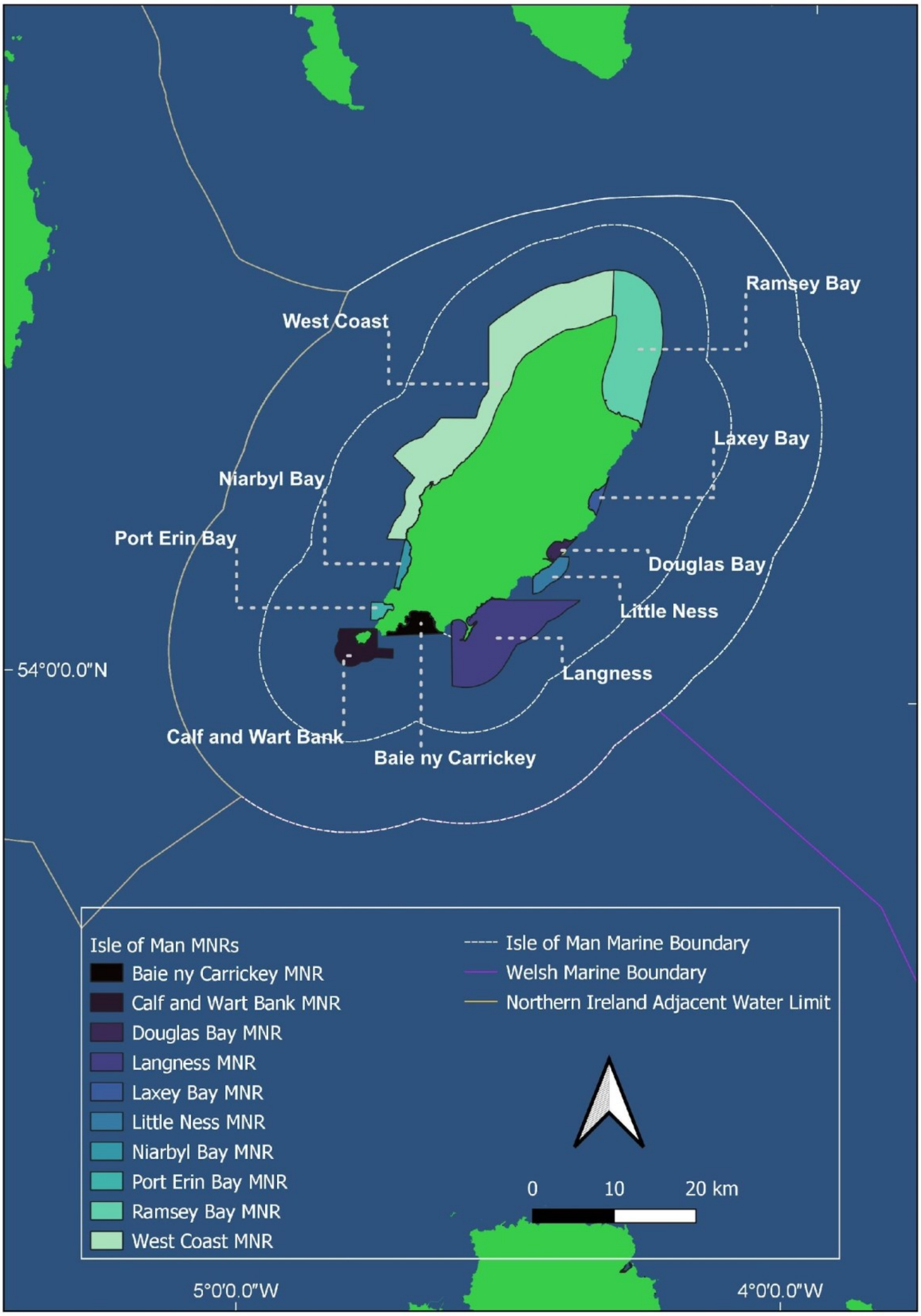


Figure 22 The Isle of Man Marine Nature Reserves (MNRs) cover 10% of the island's territorial waters, and all sit within the 3-NM limit of the island. At 4,000 km^2 the territorial sea of the Isle of Man represents just under 90% of the total jurisdiction of the country.

4.2 Active blue carbon research in the Isle of Man Territorial Seas

There are multiple projects currently under way in the Isle of Man with the aim of generating a better understanding of (1) the extent and distribution of blue carbon ecosystems, (2) how much carbon is stored within those extents, and (3) whether there is potential to enhance the carbon storage capacity of these ecosystems while at the same time maintaining and restoring the biodiversity and other services that they provide. The Manx Blue Carbon Project is run by the Department of Environment, Food and Agriculture (DEFA) and funded by the Climate Change Transformation Fund. The Blue Carbon Project is currently working with academic partnerships including PhDs with Swansea University and the National Oceanography Centre (NOC) to develop an inventory of Manx blue carbon ecosystems and identify threats and restoration opportunities to inform management. This includes a Bangor University study to quantify the effect of mobile bottom fishing on Isle of Man seabed blue carbon. The Manx Wildlife Trust is currently helping to map the extent of eelgrass beds.

Data in the following section, including shapefiles and point data, were provided from the ongoing blue carbon project for the purpose of this report (Rowan Henthorn, DEFA, personal communication, February 2023). Data were also downloaded from the marine archive (www.DASSH.ac.uk), and sediment data were taken from the EUSeaMap (2019).

4.2.1 Blue carbon seabed habitats in the Isle of Man Territorial Seas

As well as the habitats created by coastal vegetated ecosystems, the seafloor around the Isle of Man creates habitats for several commercially and ecologically important species. In 2009, seabed sediment types and communities were classified for 154 sites in Manx waters into seven main community types (Hinz *et al.,* 2009) (see Table 16).

Table 16. The seven main communities identified in the Isle of Man Territorial Seas seabed analysis (Hinz et al.*, 2009).*

	Description	Communities	Location guide
A	Areas of high current	*Alcyonidium diaphanum* *Asterias rubens*	North coast
B	Deeper water with muddy substrates	*Nephrops norvegicus* Polychaetes with emergent tubes *Sagartia* species	Offshore to the west and regions in the east
C	Brittlestar (*Ophiothrix fragilis*) beds	Hydroids Polychaete tubes Hermit crabs Queen scallops	Mainly to the east side offshore, with some regions in the north-west
D	Coarse substrates	Top shells of the genus *Gibbula* *Nemertesia antennina* *Glycymeris glycymeris*	Large portion of the south-west coast and regions off the north coast
E	Sand and gravel substrates	*Ophiura albida* Hydroids Polychaete tubes Hermit crabs Queen scallops	Distributed to the east and off the south-west coast
F	Algal and hydroid turfs		Regions in the north-east, and west coast
G	Coastal areas	*Laminaria* species Other algae Polychaete tubes *Anthopleura ballii*	Coastal/shallow areas on the north coast near Ramsey, south near Castletown and Port St Mary

The habitats of international conservation importance identified in the survey included horse mussel (*Modiolus modiolus*) beds, maerl beds and *Sabellaria spinulosa* reefs, which are all OSPAR priority habitats. The known locations of the priority features (*M. modiolus, S. spinulosa* and maerl) have been improved since the original surveys (in 2009), and more detailed point data are available (see Figure 23). The surveys were conducted not only to improve knowledge of the Isle of Man benthos, but also to guide and effectively manage the commercial exploitation of valuable species such as the king or great scallop (*Pecten maximus*) and the smaller queen scallop (*Aequipecten opercularis*).

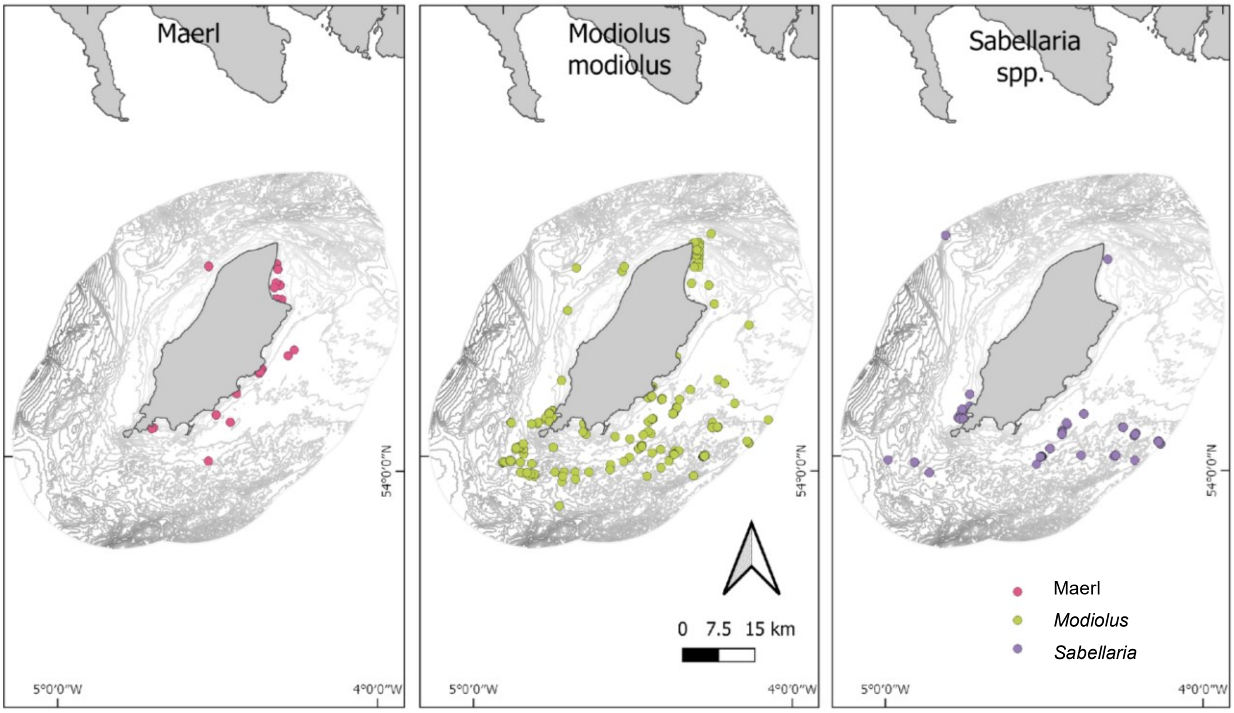


Figure 23. Current known point locations of maerl beds, Modiolus modiolus *beds and* Sabellaria spinulosa *reefs in the Isle of Man Territorial Seas. Contour lines represent depths.*

The most abundant coastal blue carbon habitats in the Isle of Man Territorial Seas are probably formed by kelp forests and seagrass beds. Anthropogenic developments around the coast and at river mouths have limited the amount of habitat available for saltmarshes to develop, and the long sandy coastlines on the east side, rocky shores to the south and large stretches of cliffs mean that saltmarsh is not a common feature on the Island. Most of the seafloor substrate (beyond the littoral zone) is made up of sand and gravel. However, within the west of the Isle of Man's territorial waters lies the Western Irish Sea Mud Belt, which consists of sandy mud and muds (see Section 4.2.6). There is also a region of slightly gravelly mud in the north-eastern part of the Isle of Man Territorial Seas, known as the eastern mud belt (UK Government, 2005).

4.2.2 Seagrass

There are currently five known areas of *Zostera marina* which are being mapped in the Isle of Man Territorial Seas. Combining the current shapefile areas gives a coverage of 2.49 km^2. The largest of these, in Ramsey Bay, is estimated to be just under 2.1 km^2 in area, representing over 84% of the known seagrass around the island. Mapping of seagrass is in its early stages and comparing existing data points from other sources (see Figure 24a) suggests that there are larger areas to be mapped and included (see Figure 24b). These estimates are likely to change as the blue carbon programme proceeds on the Isle of Man and confidence about mapped extents improves. There are no records of the intertidal species of dwarf eelgrass (*Zostera noltii)* in the Isle of Man Territorial Seas.

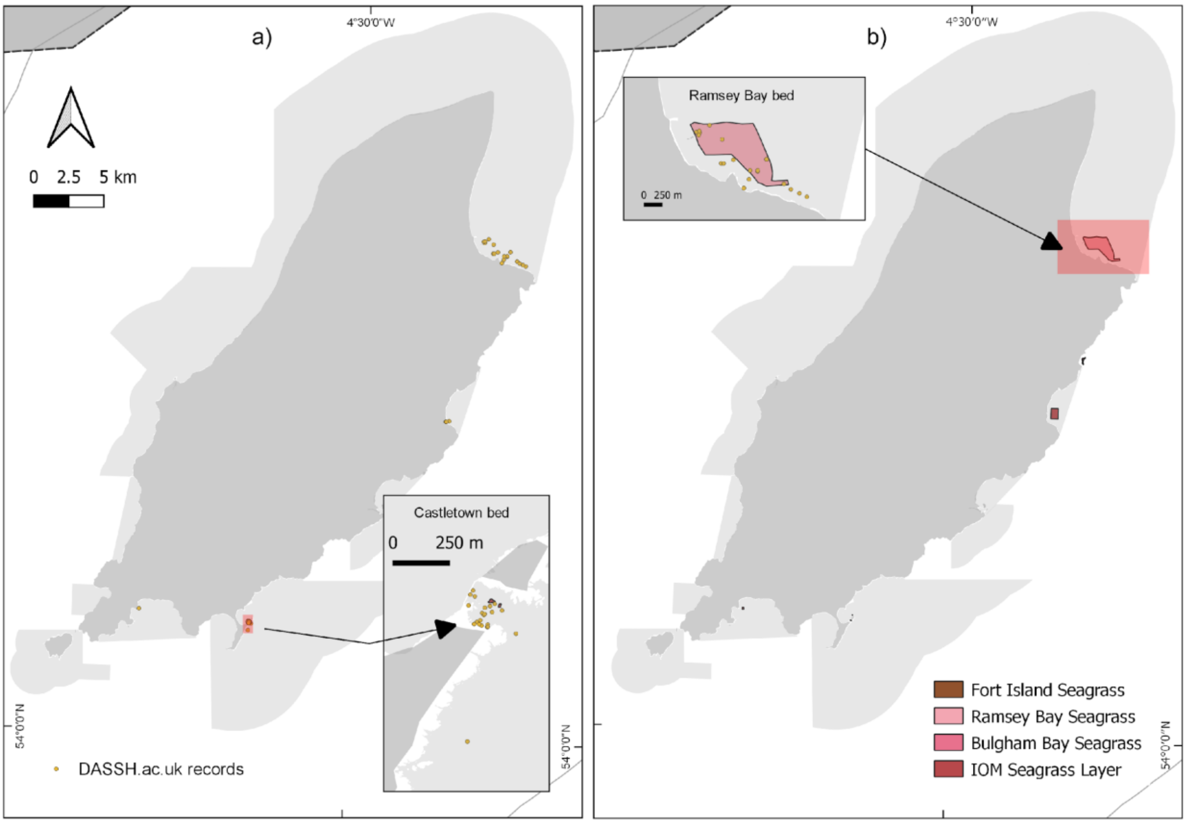


Figure 24 (a) Point data from the Archive for Marine Species and Habitats Data (www.DASSH.ac.uk). (b) Shapefiles produced to date from the Manx Blue Carbon Project. Seagrass beds within the Isle of Man Territorial Seas are currently being mapped, and data from www.DASSH.ac.uk show that the Ramsey Bay and Fort Island seagrass patches may be more extensive than was suggested by mapping of existing shapefiles.

4.2.3 Kelp beds

Some of the seminal bodies of research on kelp forest ecology and distribution in the UK were conducted on the Isle of Man. The work of Joanna Kain (see Kain, 1979) is still considered relevant in today's ecosystems throughout the UK, and was conducted on the island in the 1970s (Smale *et al.*, 2013). Kelp forest research continued in the 1980s, with canopy removal experiments finding that competition between macroalgae and the canopy effect of larger kelp species determines the community structure found within different habitats (Hawkins and Harkin, 1985). It follows that the importance of kelp forests around the island is still recognised, and six of the MNRs in the Isle of Man Territorial Seas have kelp forests listed as a key feature for protection. The locations of kelp forests in the Isle of Man Territorial Seas are well known but not mapped accurately, so existing models (for details of the methodology see Section 2.3.2 and Burrows *et al.*, 2021) have been used to estimate the extent of kelps around the island (see Figure 25). Also presented are point-source observations of three kelp species from the Archive for Marine Species and Habitats Data (see Figure 26).

Modelled biomass patterns predict that the west coast of the Isle of Man is highly suitable for kelp (see Figure 25). Although this is a dynamic, tide-swept area, it is not known to have much kelp habitat, and has only limited records of the presence of kelp (see Figure 26). Kelp forests are typically areas where biomass exceeds 5 kg/m^2. Using values that exceed 5 kg/m^2 as a threshold, the sum of the area where kelp is predicted gives an estimate of 20 km^2 for kelp forest extent in the island, and 12,800 t C for the biomass of plants.

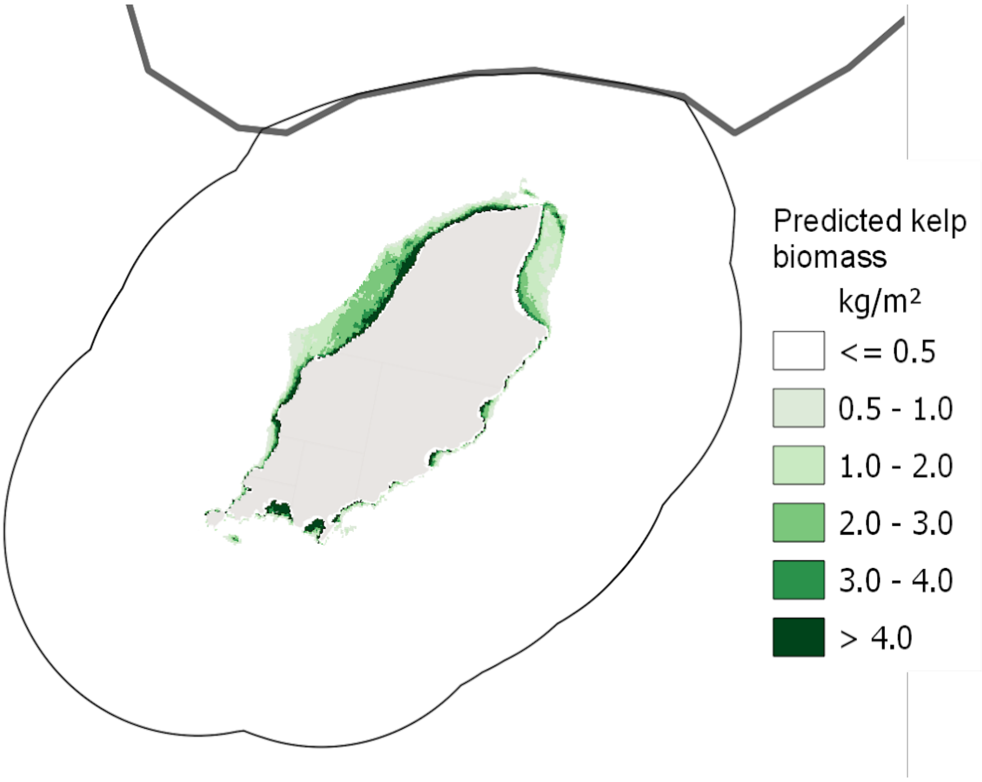


Figure 25. Modelled kelp biomass in the Isle of Man Territorial Seas. Predictions account for depth effects on kelp, but are not driven by the availability of the necessary rocky substratum: areas of sandy seabed to the north-west of the island are predicted to have high biomass but lack kelp.

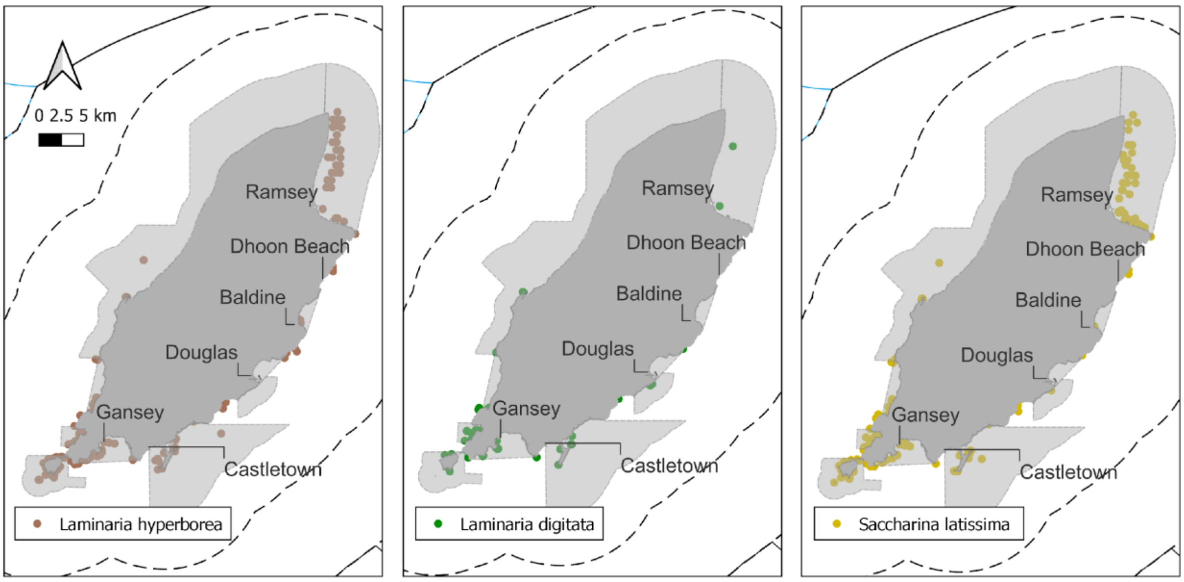


Figure 26. Observed locations of kelp within the Isle of Man Territorial Seas from the Archive for Marine Species and Habitats Data (www.DASSH.ac.uk, which includes Seasearch data points). Each circle represents an observation of the specific species. Grey areas represent MNRs (see Figure 22).

4.2.4 Saltmarsh

The coastline of the Isle of Man is dominated by sweeping sandy shorelines or rocky cliffs, and the larger river mouths are located within the bigger towns on the island. This means that there is limited suitable habitat on the island for saltmarsh to develop. The larger saltmarsh areas are situated in Ramsey to the north and near Castletown in the south. A total of 0.074 km^2 (7.4 ha) of saltmarsh habitats have been mapped around the island (see Figure 27). Saltmarsh areas are mapped in Poyll Dooey (near Ramsey), Port Cornaa, Bay ny Carrickey and in areas near Castletown and Derbyhaven. Small regions of saltmarsh have also been noted in Scarlett, Port Mooar and Dalby, but have not been included in this estimate.

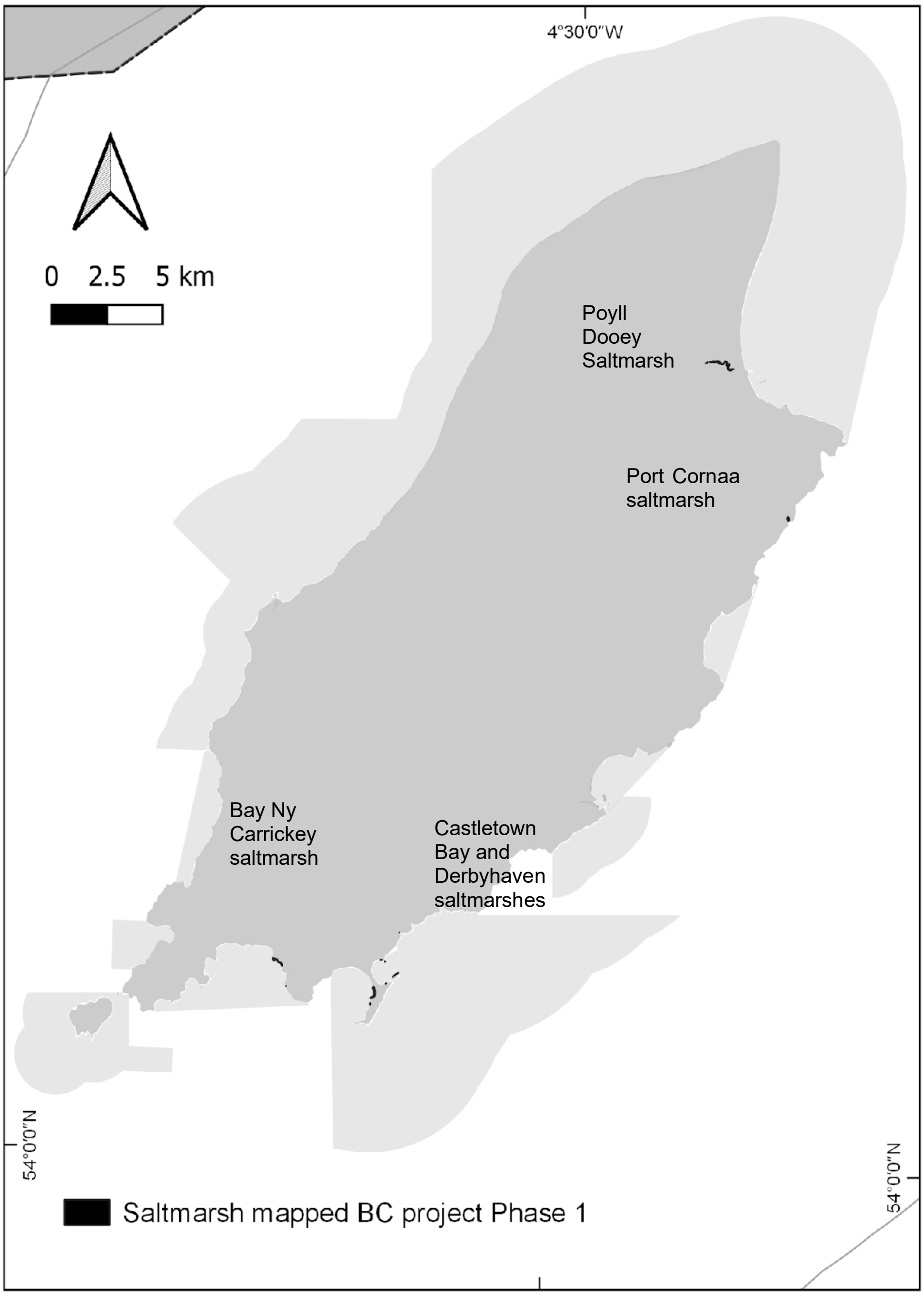


Figure 27. There is good knowledge of the extent of saltmarsh habitats in the Isle of Man Territorial Seas, and shapefiles show a total of 0.074 km^2 of saltmarsh areas. Light grey areas represent MNRs of the Isle of Man (see Figure 22).

4.2.5 Sediments within the Isle of Man Territorial Seas

The main sediment type within the Isle of Man Territorial Seas is described as coarse sediment or subtidal sand. This type of sediment provides suitable habitat for scallops and supports the fisheries in the region. Part of the Western Irish Sea Mud Belt runs through the western region of the Isle of Man Territorial Seas and forms one of the largest stores of OC in the area (see Figure 28).

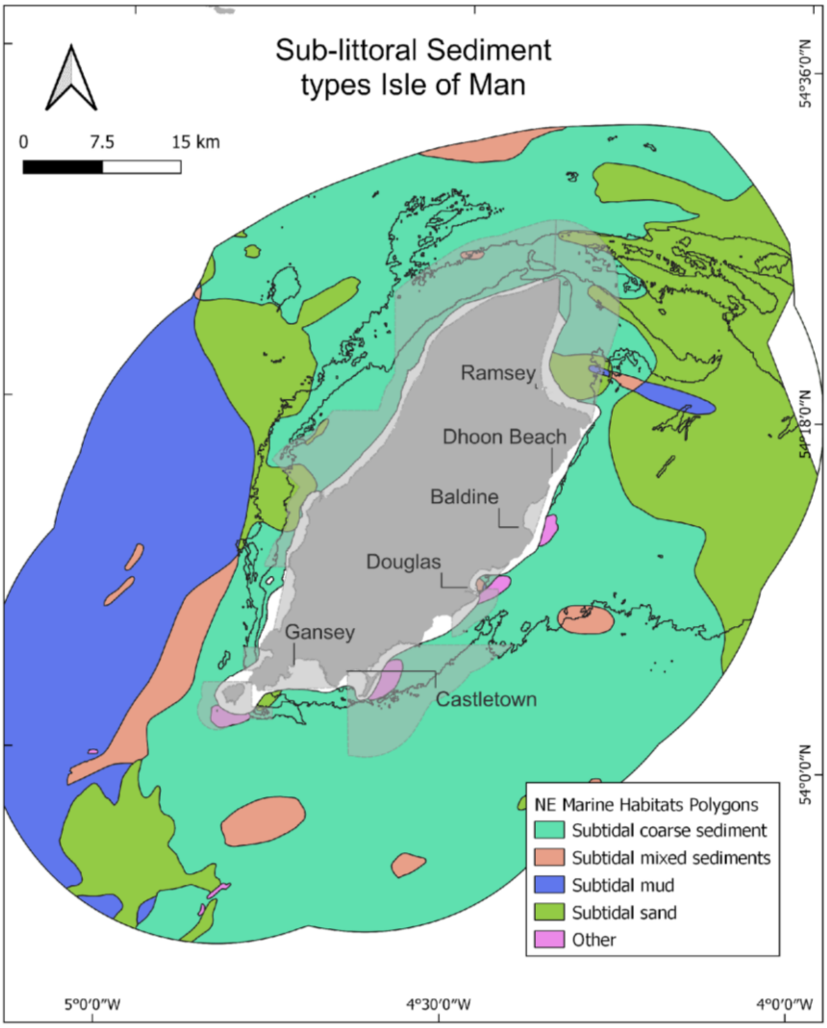


Figure 28. Sediment types around the Isle of Man. The Western Irish Sea Mud Belt to the west of the region is probably the largest store of OC in the region. Grey areas show NMRs (see Figure 22).

4.3 Carbon storage and sequestration

To provide an initial conservative estimate of the extent, biomass, productivity and storage capacity on the Isle of Man (see Table 17), the mean figures from the relevant sections of the present report are used (see Tables 2, 3, 7 and 8).

Table 17 Carbon storage rates for blue carbon ecosystems within the Isle of Man territorial waters. The average carbon store values, sequestration rates and production rates for each component were taken from the relevant sections of the present report.

Habitat	Extent (km^2)	Stock ($g/C/m^2$)	Stock (tC)	Production ($gC/m^2/yr$)	Total production (1000t C/yr)	Storage rate ($gC/m^2/yr$)	Storage Capacity (1000t C/yr)
Kelp Beds	20	640	12800	685	13.7	~10% annual production	1.37
Intertidal macroalgae	20	432	8640	378	7.56	~10% annual production	0.756
Seagrass Beds	2.49	7171	13670.1	274	0.68	100.4	0.25
Saltmarshes	0.074	4367	0.32	138	10.21	129	0.04
Total	**42.56**		**35110.42**		**32.15**		**2.42**

4.4 Risks and opportunities

4.4.1 MPA management

All MPAs were re-designated as MNRs in 2018, with varying levels of protection suitable for the habitats, species or fisheries that reside within the reserves. As a result, there are currently 10 MNRs in the Isle of Man Territorial Seas, most of which are within the 0–3 NM fishery region. A total of 10.8% of the Isle of Man Territorial Seas are protected under MNR designation, but 51.8% of the inshore region (within 0–3 NM) is protected (see Table 18). Important blue carbon habitats such as kelp forests are included as features within these MNRs.

Ramsay Bay MNR is divided into five zones. Horse mussel reefs and eelgrass beds are of high importance in the reserve, as well as a conservation zone and a rocky shore zone. A fisheries management zone allows only trawling and dredging with a specific licence from the Isle of Man Government Department of Environment, Food and Agriculture (DEFA).

Management of MNRs in the region depends upon close collaboration between DEFA, fisheries science advisers, and stakeholders such as industrial and recreational users of the environment. Regionally specific management schemes are still under development. The first closed area (Port Erin Bay) was established in the Isle of Man Territorial Seas in 1989, but legislation came into force under the Wildlife Act in 1990. In 2011, Port Erin Bay became the first MNR to be established under the Marine Nature Reserve Act (2011). The Isle of Man has more recently been developing a Biodiversity Strategy (since signing the Convention on Biological Diversity on 6 August 2012), which legally binds the Isle of Man to protect a minimum of 10% of its territorial waters.

4.4.2 Fishing activities

The Isle of Man Territorial Sea was extended for all purposes from the 3-NM limit to 12 NM (or the median line) in 1991. The Isle of Man Government Department of Infrastructure (DOI) owns the seabed and subsea minerals, including hydrocarbons, and is responsible for licensing of offshore infrastructure developments. DEFA is responsible for licensing and management of fishing activity throughout the territorial waters under the Fisheries Act 2012 (of Tynwald).

Table 18. The Isle of Man Territorial Seas Marine Nature Reserves (MNRs).

MNR	Type	Area (km^2)	Area within 3 NM (%)	Start date	Designation reason	Key habitats/species
West Coast	MNR	184.82	22.24%	2018	Nesting and foraging sea birds, soft sediments, and habitats	Rocky reefs, intertidal blue mussel beds, mixed soft sediment, kelp forests
Ramsey Bay	MNR	96.98	11.67%	2011	Divided into five zones of special habitats for protection	Maerl beds, eelgrass, horse mussels, rocky shores, scallops
Laxey Bay	MNR	3.97	0.48%	2009	Fisheries and biodiversity	Eelgrass, rocky reefs, sandy seabeds, maerl
Douglas Bay	MNR	4.64	0.56%	2008	Scallop nursery and fishery	Maerl beds, rocky reefs, kelp forest
Little Ness	MNR	10.15	1.22%	2018	Biodiversity, horse mussel beds	Horse mussels, maerl, coastal habitats
Langness	MNR	88.67	10.67%	2018	Habitat protection	Eelgrass, intertidal muds, kelp forests, sea caves
Calf and Wart Bank	MNR	20.15	2.42%	2012	Bird observatory (since 1959)	Rocky reefs, kelp forest, sandbanks, Manx shearwaters
Baie ny Carrickey	MNR	11.37	1.37%	2012	Eelgrass protection, habitat protection, sustain fisheries	Rocky reefs, kelp, sea caves, eelgrass
Port Erin Bay	MNR	4.34	0.52%	1989	Scallop fisheries, experimental closures	Rocky reefs, brittlestar beds, kelp forests, stalked jellyfish
Niarbyl Bay	MNR	5.66	0.68%	2009	Fisheries management, habitat protection	Rocky reefs, kelp forests, sea caves, intertidal mussel beds
Total		430.75	51.84%			

DEFA has sole jurisdiction over fisheries management within the 3-NM limit. However, in the ‘extended territorial sea’ (i.e., the 3–12 NM area), governance of fisheries management is undertaken in accordance with the Fisheries Management Agreement 2012 (‘FMA2012’), which requires DEFA to consult with the relevant UK fisheries authorities before introducing any new management measures, and upholds a reciprocal ‘fair access’ arrangement for UK and Isle of Man vessels. Following the UK’s exit from the EU, DEFA has notified the UK Fisheries Authorities of its intention to suspend its participation in the FMA2012 due to the agreement’s governance arrangements being based upon the UK’s pre-existing obligations under the EU Common Fisheries Policy. The parties to FMA2012 are currently re-negotiating governance arrangements to reflect the UK’s new status as an independent coastal state outside of the EU Common Fisheries Policy. DEFA’s ability to regulate freely within the 3-NM area has meant that the existing network of MNRs is confined to the 0–3 NM area (i.e., the ‘coastal zone’).

Fishing restrictions within MNRs include closed regions for scallop fisheries and restrictions on commercial mobile fishing gear, dredges and trawls. Static fishing (e.g., using pots) is permitted except in eelgrass conservation zones and in relevant Ramsey Bay areas. Scallop fisheries are carefully managed in the Isle of Man Territorial Seas. The Isle of Man Scallop Management Board (SMB), which was formed by DEFA, provides advice on scallop fisheries around the Isle of Man and is a non-statutory advisory board that aims to provide advice for scallop fishery management.

After the closure of Port Erin Bay in the Isle of Man in 1989, local fishermen noticed improvements in their catches, which led them to support and initiate further closed areas (Gell *et al.,* 2013). Further initiatives were then developed with the engagement of fishermen in mind. For example, a programme was designed to actively involve fishermen (and other stakeholders) in the decisions and discussions around the designation of new protected areas, as well as a fisheries science programme specifically for fishermen that aimed to inform them about good practices and the reasons behind MNR designations (Gell *et al.,* 2013). Involving fishermen in the decision-making process allows Manx fishermen to be proactive, engaged and able to take ownership of their region, and has led to effective management of fisheries in the region.

4.4.3 Anchoring and mooring

With the exception of eelgrass conservation zones there are no restrictions on anchoring in the Isle of Man Territorial Seas. Popular places to anchor are in Castletown Bay in the south-east of the Isle of Man, in Ramsey Bay and in the St Mary anchorage just off Port St Mary. The Manx Wildlife Trust is working with the Isle of Man to raise awareness among commercial and leisure boat owners about the fragility of seagrass beds.

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6 Glossary

basin	A large depression in which sediments are accumulated, or a tectonic, circular, syncline-like depression of strata.
blue carbon	Carbon that is stored and sequestered in coastal and marine ecosystems, including tidal and estuarine salt marshes, seagrass beds and mangrove forests, associated sediment stores and biogenic reefs. For the purposes of the present report, this definition has been extended to include the geological substrate on which the marine ecosystem has developed.
carbon accumulation rate	The rate at which carbon reaches the seabed sediment, expressed in g $C/m^2/yr$ (grams of carbon per square metre per year).
carbon fixation (or capture)	The conversion of carbon dioxide (CO_2) into carbon compounds by plants.
Continental Shelf	A region of seabed at depths that are shallow compared with those in the ocean. Around Scotland is a wide area of shelf reaching about 120 metres at its outer edge (deeper in a few glacier-dredged troughs); the shelf seas, including the North and Malin Seas, are the waters over this shelf.
dry bulk density	The dry weight of sediment per unit volume of soil. It takes into account both the solids and the pore space, and is expressed as g/cm^3.
estuary	An area where fresh water comes into contact with seawater, usually in a partly enclosed coastal body of water; a mix of fresh and salt water where the current of a stream meets the tides.
gravel	Coarse-grained sediment, mainly consisting of particles larger than 2 mm in diameter, and including cobbles and boulders.
inorganic carbon (IC)	Carbon dioxide (CO_2) gas, dissolved CO_2 and bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions; particulate compounds of carbonate, such as calcium carbonate ($CaCO_3$, also known as chalk).
labile carbon	Sugars, proteins and other carbon compounds that are easily used by marine bacteria.
long-term carbon stores	Carbon that is considered to be locked away from atmospheric circulation for significant time periods (generally over 100 years).

mud	A sediment that consists mainly of grains with a diameter of less than 0.06 mm. It is a general term that refers to mixtures of sediments in water, and applies to both clays and silts.
organic carbon (OC)	Compounds of carbon, nitrogen and hydrogen and, in some cases, oxygen and sulphur, which are used by living organisms in the structure of their cells and as a source of energy.
particulate organic carbon (POC)	Organic carbon that is in the form of solid particles, derived from dead plant material.
refractory carbon	High-molecular-weight and structurally complex compounds that are difficult for marine organisms to use (e.g., lignin, humic acid).
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	Any solid particles that have settled under the action of gravity after formerly being suspended in liquid.
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?
Saltmarsh Extent & Zonation	www.data.gov.uk	Environment Agency	Environment Agency	Open Government Licence 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 Licence 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
Northern Ireland, OpenDataNI portal	www.opendatani.gov.uk/@department-of-agriculture-environment-and-rural-affairs/northern-ireland-marine-protected-areas-marine protected areas3	DAERA	DAERA	www.opendatani.gov.uk/code-of-conduct	No
Data Map Wales	Natural Resources Wales	NRW	NRW	https://datamap.gov.wales/geoserver/ows?service=WFS&version=1.0.0&request=GetFeature&typename=inspire-nrw%3ANRW_NERC_OSPAR_SEAGRASS&outputFormat=SHAPE-ZIP&srs=EPSG%3A4326&format_options=charset%3AUTF-8	No

Title	Data source	Data sub-source	Data owner	Restrictions	Permissions request needed?
Isle of Man Blue Carbon Shapefile Datasets	Rowan Henthorn, DEFA (personal communication, February 2023)		DEFA	Preliminary findings from various projects are reported with the caveat that these are active projects	Permissions granted for this report