Briefing: Blue Carbon

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Climate Change Committee

Contents

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Blue carbon

Natural ecosystems and blue carbon

The UK has committed to a legally binding target to reach Net Zero greenhouse gas (GHG) emissions by 2050. **The natural environment has a pivotal role to play in this transition, with its unique ability to sequester and store carbon** as well as providing wider climate adaptation services including biodiversity. This briefing looks at the evidence on the potential for coastal and marine ecosystems to contribute to climate mitigation and considers the associated benefits, such as for climate adaptation.

The term **'blue carbon'** is defined as marine and coastal carbon which can be managed to contribute to GHG mitigation.[1] In the UK, saltmarsh and seagrass are considered to fall into this category. Here, we also consider the potential for other marine and coastal habitats to sequester and store carbon, but which currently fall outside this strict definition.

Blue carbon and the UK GHG Inventory

Carbon in marine and coastal ecosystems is not currently included in the UK's GHG inventory. GHG inventories account for the impact of anthropogenic (human) activity on GHG fluxes, which should be separated from natural processes. The link between anthropogenic management of these ecosystems and GHG emissions is most clear for saltmarsh and seagrass ecosystems. However, there remains significant uncertainty in quantifying the contribution of marine and coastal ecosystems to carbon stores and sequestration in the UK. This is due to reasons such as localised and limited data, inconsistencies in experiment design and uncertainties about the extent and condition of marine and coastal ecosystems.

Despite the uncertainties, our review of evidence suggests that the **restoration and creation of saltmarsh and seagrass ecosystems is likely to yield an additional GHG abatement of well below 1 $MtCO_2e$/yr.** This is small when considered against the emissions from the wider economy (405.5 $MtCO_2e$ in 2020), and actions on blue carbon to pursue this should be proportionate to its scale. Marine and coastal ecosystems do, however, represent potentially very large natural carbon stores and may provide extremely efficient carbon removal on a local scale. **Their protection and restoration is important** to reduce their physical loss from habitat degradation, damaging activities and the associated GHG emissions.

We make four recommendations:

- **Inclusion in the GHG inventory.** BEIS should produce a roadmap to inclusion of saltmarsh and seagrass in the GHG inventory, which specifies a suggested level of inclusion* (i.e., Tier 1, 2 or 3), the additional data required to facilitate this, and an indicative timescale to inclusion.

- **Monitoring.** Efforts to monitor, understand and analyse changes in the extent, condition and functioning of marine and coastal ecosystems should be encouraged, including an assessment of the risks these present to emissions and wider ecosystem value, and with reference to the changing climate and other pressures.

* The IPCC Wetlands supplement has guidance which indicates the minimum evidence required for GHG inventory inclusion (Tier 1), country-specific emissions factors (Tier 2) or employing modelling approaches (Tier 3).

- **Protection and restoration.** The UK government and devolved administrations should continue to strengthen protection and restoration in marine areas, and support efforts to sustainably manage marine and coastal ecosystems, giving due consideration to their carbon value.

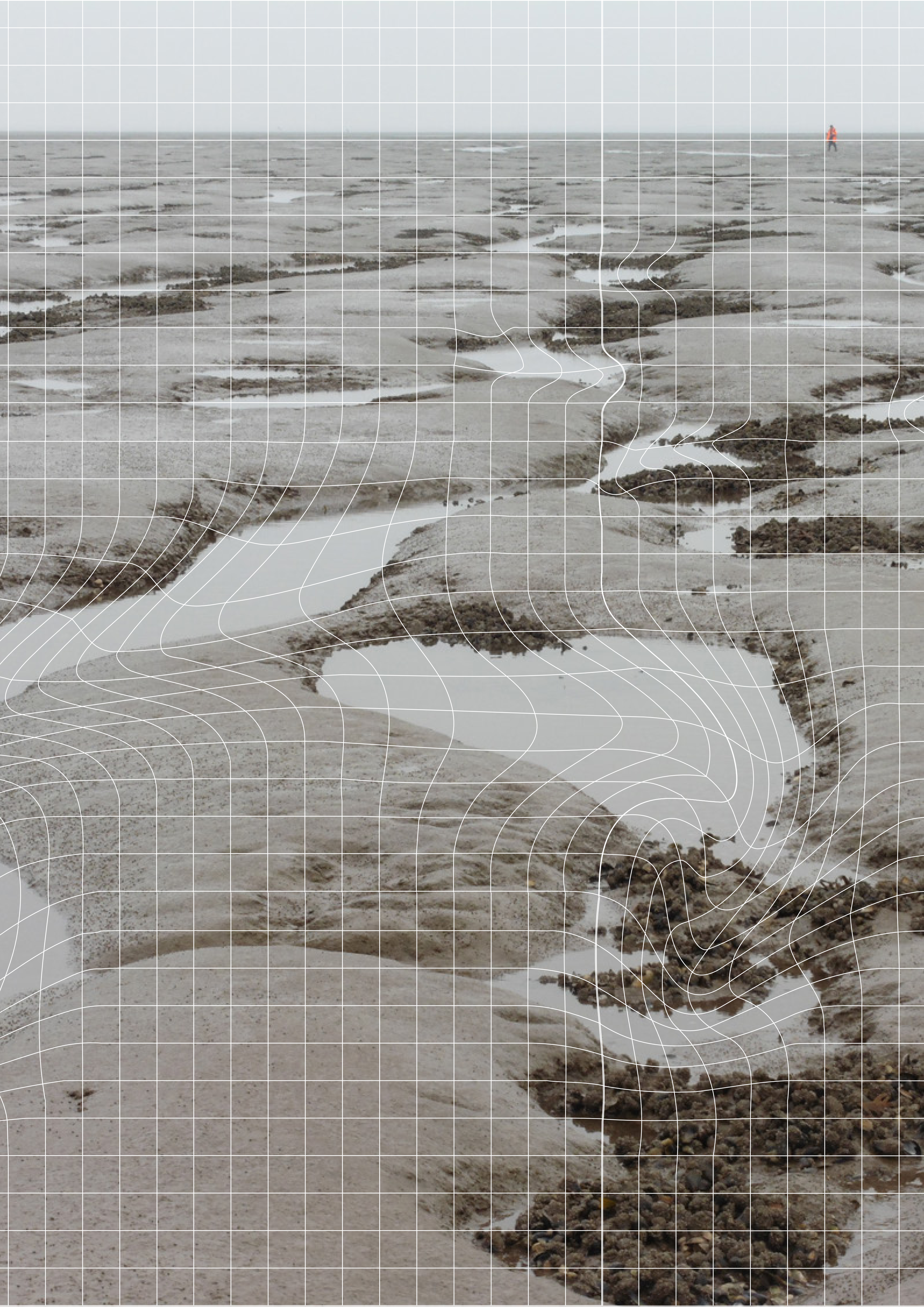
- **Blue carbon in land policy.** The interaction of marine and coastal ecosystems with wider catchments should be recognised in the design of initiatives to replace the Common Agricultural Policy, and opportunities for use of wider policy levers to deliver better management should be pursued.

Endnotes

[1] Lovelock and Duarte (2019) *Dimensions of Blue Carbon and emerging perspectives. Biology Letters*, https://doi.org/10.1098/rsbl.2018.0781

Chapter 1

Introduction



1. Greenhouse gas removal by natural ecosystems

The natural environment has a unique ability to remove carbon from the atmosphere, and store it in vegetation, soils, and sediments.

Natural systems actively remove carbon dioxide (CO_2) by photosynthesis from the atmosphere, converting it into organic carbon. This is termed carbon sequestration.

- This organic carbon can be stored in vegetation, soils, and sediments over a range of timescales. These are referred to as carbon stores.
- Damage or disturbance of these carbon stores can result in the oxidation of this carbon to CO_2, and its subsequent release back into the atmosphere, constituting an emissions source.[1]

Habitat creation or restoration has the potential to increase carbon sequestration, while habitat protection avoids emissions and may enhance carbon sequestration. Most previous work in this area has focused on terrestrial systems, such as woodlands and peatlands.

In contrast, management of carbon in UK marine and coastal ecosystems has received comparatively little attention. They also have a wider importance extending beyond their carbon value, with significant implications for biodiversity, fisheries, water quality and coastal flood risk management.[2,3,4]

Here we review the evidence regarding the extent to which carbon is sequestered and stored in the UK's marine and coastal ecosystems, the implications for the UK's GHG inventory, and wider associated benefits.

2. What is blue carbon?

Blue carbon is defined as marine and coastal carbon fluxes or stores which can be managed to contribute to GHG mitigation.

The term **'blue carbon'** is defined as marine and coastal carbon fluxes or stores which can be managed to contribute to GHG mitigation.[5] In the UK, saltmarsh and seagrass are considered to fall into this category. Here, we adopt this strict definition, but note that other reports have used the term to describe carbon across the full suite of marine and coastal ecosystems and we therefore consider them within this assessment.

Marine and coastal ecosystems play an **important role in Earth's carbon cycle** through their ability to sequester and store considerable amounts of carbon. This occurs through photosynthesis and subsequent carbon burial in sediments and soil. Alongside sequestered carbon, they also physically trap and store carbon from other terrestrial and marine 'donor' habitats (Box 1). This mitigation potential is being increasingly recognised, and the contribution of coastal zones is now included in global carbon budget reporting by the Intergovernmental Panel on Climate Change (IPCC), while habitat restoration projects in the UK are developing our understanding of blue carbon as a nature-based solution to mitigate climate change.[6]

UK marine and coastal ecosystems have suffered widespread degradation.

However, carbon stored in marine and coastal ecosystems is sensitive to disturbance:

- Across the UK, marine and coastal ecosystems have suffered widespread decline[7,8] from impacts such as physical modification and disturbance, pollution, and disease. They are also highly sensitive to the impacts of climate change.[9]

- The capacity of marine and coastal ecosystems to store and accumulate organic carbon in their sediments and vegetation means that anthropogenic activities that impact these ecosystems will have implications for the UK's GHG emissions.

- When degraded or lost, these ecosystems can become sources of emissions. Degradation may also limit their capacity to provide vital environmental services, such as mitigation of flood risk and coastal erosion, and benefits for biodiversity, water quality and fisheries.

- Conversely, their effective management may provide climate change mitigation benefits by enhancing carbon sequestration and protecting carbon stores to avoid emissions.

- Effective management can also enhance their provision of wider environmental and climate adaptation benefits.

There is uncertainty in quantifying the contribution of blue carbon ecosystems to carbon stores and sequestration in the UK.

Carbon in marine and coastal ecosystems is not currently included in the UK's GHG inventory (Box 1). There remains significant uncertainty in quantifying the contribution of these ecosystems to carbon stores and sequestration in the UK:

- Studies are typically localised and the limited data available demonstrates high regional variability, making country-wide estimates difficult. For some habitats, such as seagrass meadows, there is reliance on data from international studies.

- There is inconsistency in data reporting and experimental design. Carbon store assessments are not standardised, with studies reporting stores to a range of sediment depths.[10,11] To facilitate comparisons, carbon stores require extrapolation to estimate the store to the same sediment depth, potentially introducing further uncertainty. Additionally, studies may or may not consider vegetation carbon or gases other than CO_2. Standardisation of measurement procedures would be highly beneficial.

- A lack of long-term studies means the response of carbon accumulation to management, including restoration, is poorly defined across marine and coastal ecosystems.

- There remain uncertainties about the extent and condition of marine and coastal ecosystems in UK waters.

However, understanding of these issues is increasing as research expands. The following sections review the evidence on carbon stored and accumulated in the UK's marine and coastal ecosystems, the potential for inclusion of blue carbon in the UK's GHG inventory, and the wider associated co-benefits provided by marine and coastal ecosystems.

Box 1
GHG inventories: anthropogenic activities and habitat connectivity

The inventory includes GHGs related to specific anthropogenic activities.

Carbon cycling in marine and coastal ecosystems is driven by a combination of natural processes and human activities. Therefore, while marine and coastal carbon is not currently included in the UK's GHG inventory, estimates of current carbon fluxes in these ecosystems should not be interpreted as "missing" from the inventory:

- GHG inventories do not (ideally) include natural GHG fluxes.
- Rather they are concerned with those which are clearly attributable to specific anthropogenic activities. Inventory inclusion depends on evidence-based estimates of additional GHG emissions or sequestration associated with those activities.
- However, in some cases it can be difficult to distinguish the relative contributions of anthropogenic activities and natural processes.
- In these instances, the **'managed land proxy'** may be relevant – this assumes that, if land is managed, anthropogenic fluxes dominate.

Inventory inclusion is evidence-based. Addition of a new term to the UK's GHG inventory requires both:

- Identification of an anthropogenic activity which causes additional GHG emissions or sequestration.
- Transparent, robust, and evidence-based estimates of those changes in GHG fluxes.

Since 2014, the IPCC Wetlands supplement has set out guidelines for including blue carbon habitats, including saltmarsh, seagrass, and mangroves in national GHG inventories:

- This reflects their status as blue carbon ecosystems, with clear links between specific anthropogenic activities and increased emissions or sequestration of GHGs.
- The guidance indicates the minimum evidence required for inventory inclusion (a "Tier 1" approach), as well as advice on developing more accurate estimates, for instance by developing country-specific emissions factors ("Tier 2") or employing modelling approaches ("Tier 3").

IPCC guidelines do not exist for other coastal and marine ecosystems. However, the UK does have the option to include activities related to these ecosystems **if the evidence is sufficient to do so.**

Coastal and marine ecosystems are part of catchments. Understanding the connectivity of terrestrial, coastal and marine ecosystems is crucial to their inclusion in the inventory:

- In some ecosystems (e.g., saltmarshes and seagrass meadows), vegetation sequesters carbon by photosynthesis, and this carbon is stored in situ in soils or sediments. This is termed **autochthonous carbon.** The *accumulation* of autochthonous carbon derived from photosynthesis results in net *sequestration* of CO_2.
- However, marine and coastal ecosystems can also accumulate carbon which has been transported from other terrestrial, coastal, and marine habitats. This carbon, which derives from outside the environment in question, is termed **allochthonous carbon.**
- For instance, marine and coastal ecosystems may receive carbon from terrestrial sources, such as peatlands and agricultural land, via water pathways. This transport via fluvial processes means terrestrial, coastal and marine ecosystems form wider, interconnected catchments.

Ideally, the UK's GHG inventory would account for carbon at each stage of its transfer through the catchment. While it is difficult to assess whether the full suite of transfers has been accounted for, it is clear that the vegetation and sediments of marine and coastal ecosystems currently represent a missing term.

Source: IPCC (2014) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*; Lovelock and Duarte (2019) *Dimensions of Blue Carbon and emerging perspectives*; Gregg et al. (2021) *Carbon storage and sequestration by habitat: a review of the evidence (second edition)*.

Endnotes

[1] Pendleton et al. (2012) *Estimating Global ''Blue Carbon'' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems*. *PLoS ONE,* https://doi.org/10.1371/journal.pone.0043542

[2] Environment Agency (2021) *Achieving net zero A review of the evidence behind potential carbon offsetting approaches*, https://assets.publishing.service.gov.uk/media/60cc698cd3bf7f4bcb0efe02/Achieving_net_zero_-_a_review_of_the_evidence_behind_carbon_offsetting_-_report.pdf

[3] Fairchild et al. (2021) *Coastal wetlands mitigate storm flooding and associated costs in estuaries. Environmental Research Letters,* https://doi.org/10.1088/1748-9326/ac0c45

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[9] Berry, P. and Brown, I. (2021) *National environment and assets.* In: *The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)].* Prepared for the Climate Change Committee, London, https://www.ukclimaterisk.org/independent-assessment-ccra3/technical-report/

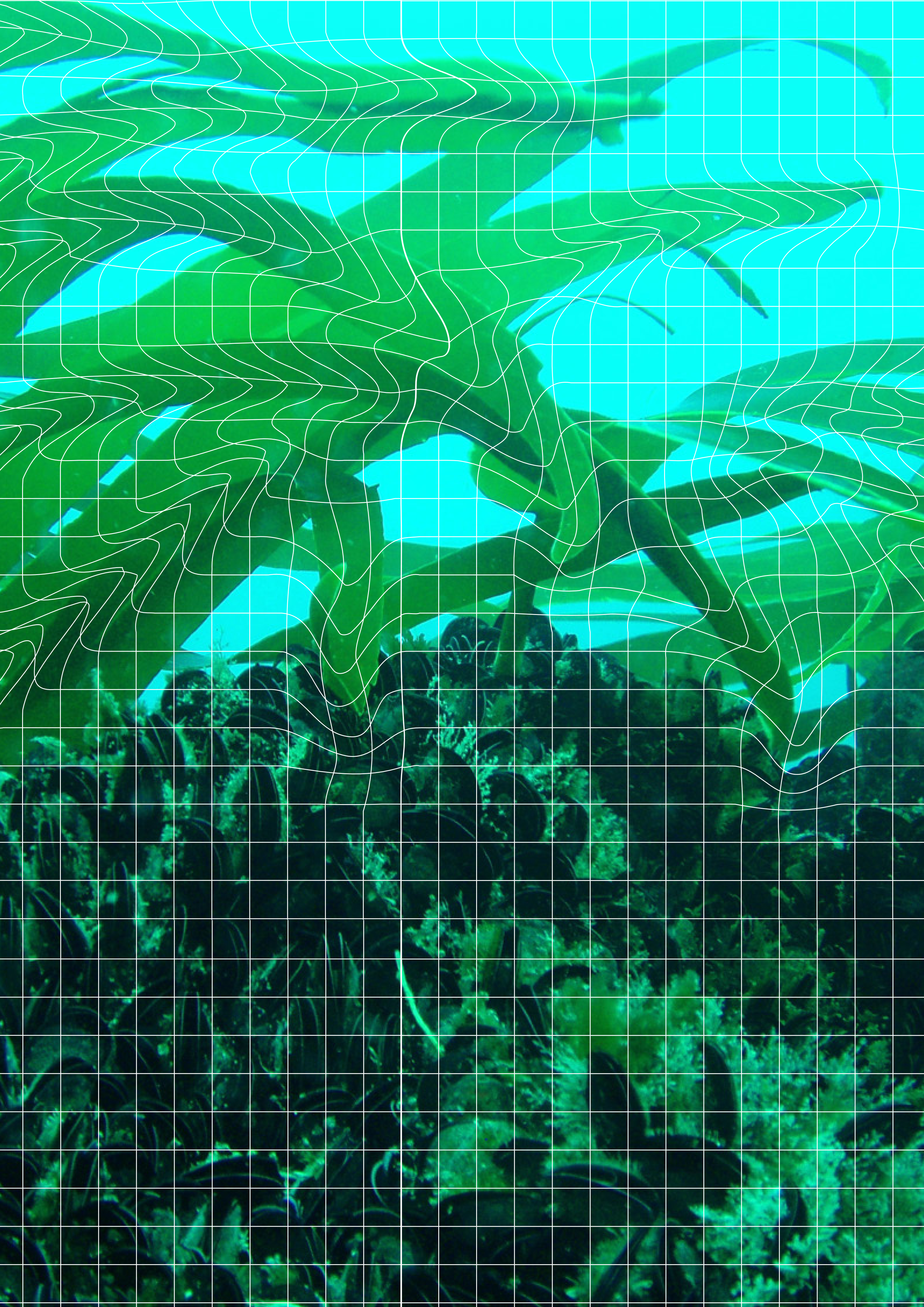
[10] Austin et al. (2021) *Blue carbon stock in Scottish saltmarsh soils. Scottish Marine and Freshwater Science,* https://data.marine.gov.scot/dataset/blue-carbon-stock-scottish-saltmarsh-soils

[11] Burden et al. (2019) *Effect of restoration on saltmarsh carbon accumulation in Eastern England. Biology Letters,* https://doi.org/10.1098/rsbl.2018.0773

Chapter 2

Carbon in marine and coastal ecosystems

In this chapter we present estimates of carbon storage and accumulation by marine and coastal ecosystems within the UK's Exclusive Economic Zone (EEZ) reflecting a mixture of natural and anthropogenic processes. This includes the potential contribution to climate change mitigation under specified management activities, and areas of uncertainty.



1. Carbon storage and accumulation

The UK's marine and coastal ecosystems are potentially highly significant in their contribution to the natural storage and accumulation of carbon, despite the uncertainties set out previously. Within the UK's EEZ*:

Marine and coastal ecosystems accumulate very large stores of carbon.

- **Marine sediments** (both subtidal and intertidal) contain far larger organic carbon stores, due to their substantial area. It has been estimated that the top 10cm of marine sediments in the UK's EEZ contain organic carbon equivalent to some 1900 $MtCO_2e$[1] (Figure 1.2).

- **Carbon accumulation in selected marine and coastal ecosystems** (saltmarsh, seagrass meadows, intertidal and continental shelf† sediments) totals an estimated 11 $MtCO_2e$/yr.[2] This estimate represents only a small fraction (13%) of the total area of the UK's EEZ. It may, therefore, be an underestimate, and higher values have been suggested.[3,4]

- However, much of the carbon accumulated in marine soils and sediments will be derived from the large amounts of carbon stored in the water body itself, rather than the atmosphere**. Therefore, it won't necessarily result in a reduction of atmospheric CO_2**, as that is dependent on regional factors and timescales under consideration.

The UK GHG inventory accounts for the impact of human activity on GHG fluxes.

The UK's GHG inventory is concerned with emissions sources or sinks which are demonstrably associated with specific anthropogenic management activities (Box 1):

- The estimates of carbon storage and accumulation presented here relate to marine and coastal ecosystems in their current state, reflecting a mixture of natural and anthropogenic processes. Natural processes dominate, with the anthropogenic contribution making up a small proportion of overall carbon storage and accumulation.[5]

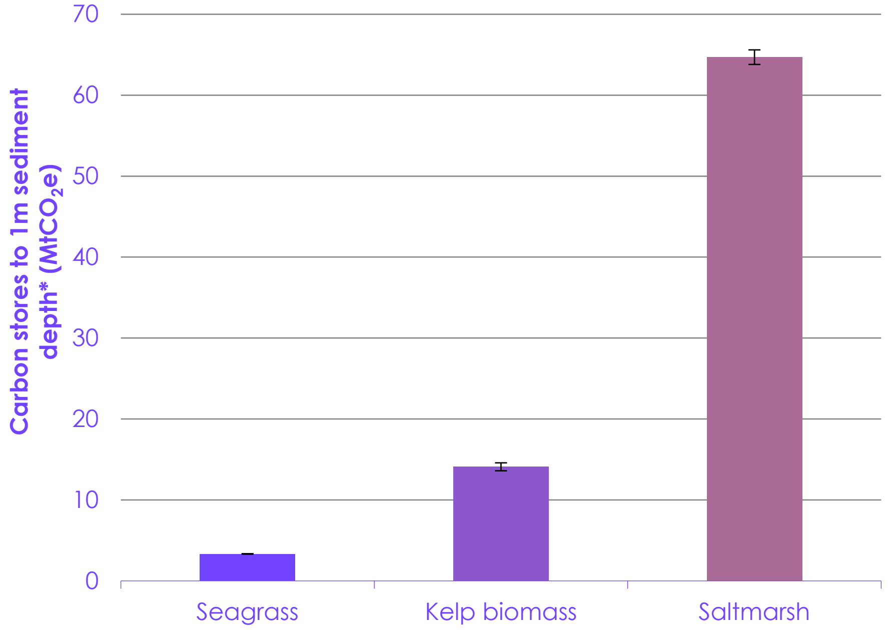
- The distinction between anthropogenic and natural processes is important, as such estimates should not be interpreted as additional anthropogenic terms that are "missing" from the UK's current GHG inventory.

An assessment of blue carbon ecosystems in the context of national emissions reporting follows in section 3 – 'Marine and Coastal Ecosystems in the UK GHG Inventory'.

* The UK's EEZ is defined as the area under the territorial ownership of the UK. In this report, estimates relate to the UK's local EEZ, thereby excluding areas related to the UK's Overseas Territories.

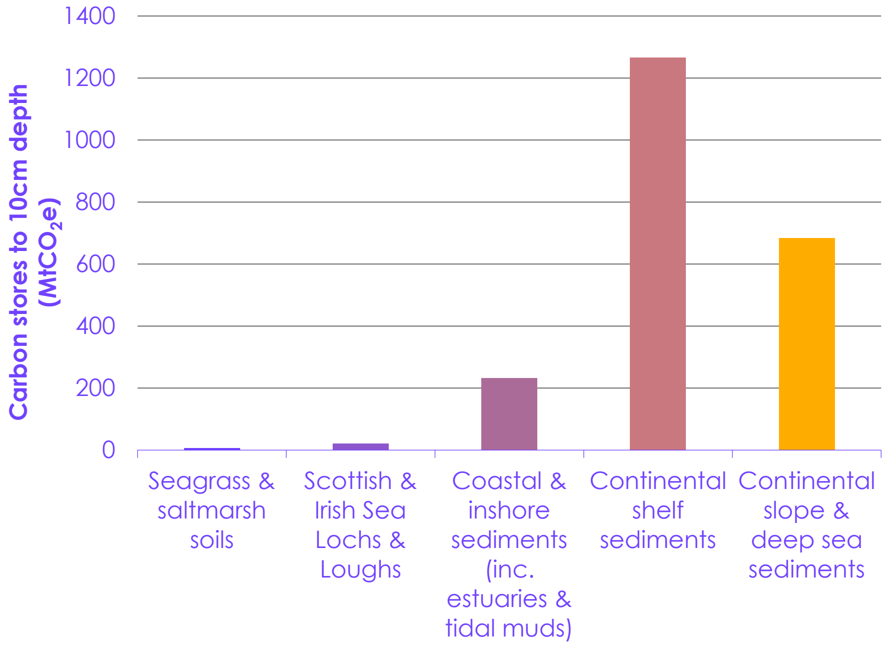
† The continental shelf is defined as the area of seabed adjacent to the UK, and reaches water depths of around 200m. The continental slope refers to the region of sharply increasing water depth at the edge of the continental shelf, marking the transition to deep-sea environments.

Figure 1.1 Total carbon stores in vegetated coastal ecosystems (UK EEZ, 1m soil depth where applicable)



Source: Parker et al. (2021) *Blue Carbon stocks and accumulation analysis for Secretary of State (SoS) region.*
Notes: All values calculated to 1m sediment depth except kelp. Value for kelp relates to carbon stored in kelp biomass.

Figure 1.2 Marine sedimentary carbon stores (UK EEZ) compared to saltmarsh and seagrass soils



Source: Smeaton et al. (2021) *Marine Sedimentary Carbon Stocks of the United Kingdom's Exclusive Economic Zone.*
Notes: Calculation of saltmarsh and seagrass stores to 10cm soil depth assumes uniform C distribution with depth and preferred to extrapolation of sediment carbon stores, given that saltmarsh and seagrass stores in figure 1.1 had already been extrapolated to 1m soil depth.

Saltmarshes: current stores and accumulation

Saltmarshes are vegetated coastal habitats which are periodically flooded at high tide. Saltmarsh vegetation sequesters carbon by photosynthesis, and this carbon can be accumulated (buried) in saltmarsh soils along with a proportion of transported carbon (Box 1). Though carbon accumulation is extremely efficient on area basis[6,7] (Figure 2.1), saltmarshes are restricted to narrow regions around the coastline and have suffered significant reduction in areal extent due to habitat degradation. Current extent in the UK is estimated at around 450 km^2 (less than 0.1% of the area of the UK's EEZ)[8], therefore the total capacity to accumulate and store carbon is relatively small (Figures 1.1 and 2.2):

Saltmarshes can accumulate high rates of carbon. They are found in coastal regions but have reduced in area extent due to habitat degradation.

- **Accumulation**: It is estimated that UK saltmarshes currently accumulate carbon equivalent to 0.24 $MtCO_2e$/yr.[9] Key uncertainties in this figure include:
  - The total area of saltmarsh in the UK remains uncertain.
  - Substantial geographic and temporal variability in accumulation rates results in a wide range of values (Figure 2a). [10, 11] Further, because some geographic regions have been more densely sampled than others, average values are likely to be affected by geographic bias. Here, we use an average value of 136 $gC/m^2/yr$ (1.36 tC/ha/yr),[12] but recognise that other studies have reported much higher and lower values.[13]
  - The average accumulation rate used here is derived from managed, restored and near-natural saltmarshes. This creates the possibility of sampling bias, with evidence suggesting that accumulation rates may differ between natural and restored saltmarshes,[14] and that accumulation rates may be affected by land management (e.g., grazing).[15]
- **Storage:** Saltmarsh carbon stores (1m sediment depth) are estimated to total 65 $MtCO_2e$.[16] Again, these estimates are subject to uncertainty:
  - Saltmarsh carbon stores are known to exhibit substantial geographic variability.[17] Here, we use an average value of 36.8 kgC/m^2 (368 tC/ha), to 1m sediment depth.[18]

Seagrass meadows: current stores and accumulation

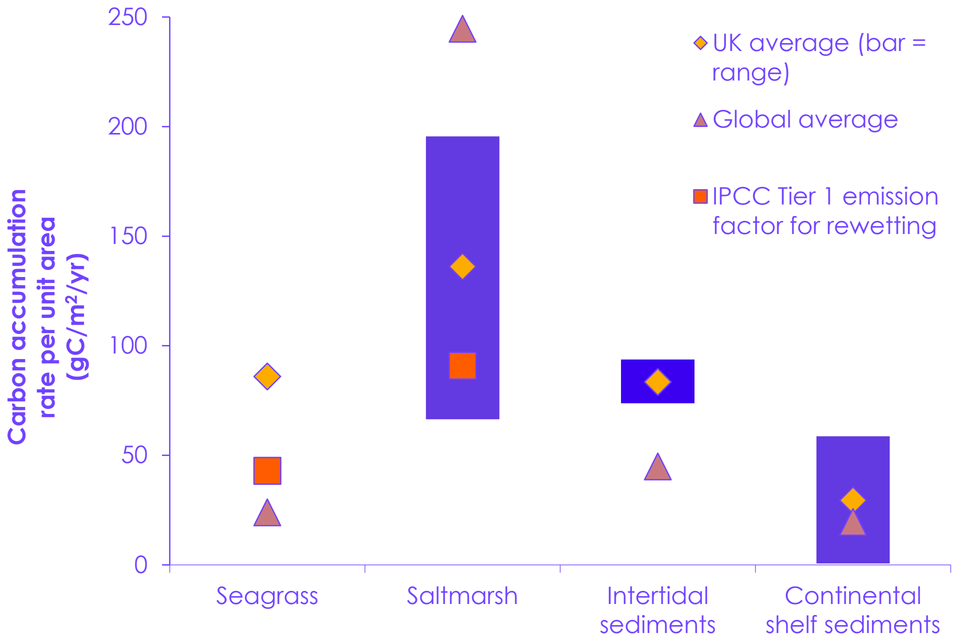
Seagrasses form underwater meadows in shallow waters.

Seagrasses are aquatic plants which form submerged meadows in shallow marine ecosystems. As in saltmarshes, carbon is sequestered by photosynthesis and can be accumulated in seagrass soils along with carbon transported from outside the habitat (Box 1). Carbon storage and accumulation in UK seagrass meadows is highly uncertain. This is due to uncertainty regarding their extent - most estimates suggest there are between 70 and 90 km^2 in the UK's EEZ[19, 20] - and the very limited data regarding carbon accumulation rates and soil carbon density:

There are no UK based estimates of carbon accumulation by seagrass systems.

- **Accumulation:** There are **no estimates of carbon accumulation rates in UK seagrass ecosystems.** While carbon accumulation rates have been measured elsewhere [21, 22] (Figure 2.1), it is unknown whether these accumulation rates are representative of UK ecosystems.[23] UK specific data are urgently needed to improve the robustness of these estimates.
  - It has been suggested that carbon accumulation rates measured in 11 sites in the temperate US (average 86 $gC/m^2/yr$ (0.86 tC/ha/yr))[24] may be most representative of UK ecosystems.[25]
  - Using this accumulation rate UK seagrass ecosystems are currently estimated to accumulate around 0.02 $MtCO_2e/yr$.[26]
  - However, accumulation rates show significant geographic variation, and the global average value suggests slower accumulation than assumed here (Figure 2.1).[27]
- **Storage:** UK seagrass meadows are estimated to store around carbon equivalent to 3 $MtCO_2e$ (to 1m depth).[28]
  - As for saltmarshes, geographic variability in stores [29] and variable measurement depths[30, 31] are key sources of uncertainty in this estimate.
  - Here, we use an average value of 13 kgC/m^2 (130 tC/ha), to 1m sediment depth.[32] This value is derived from data from just three studies, and estimates could be made more robust by increasing data coverage from UK seagrass ecosystems.

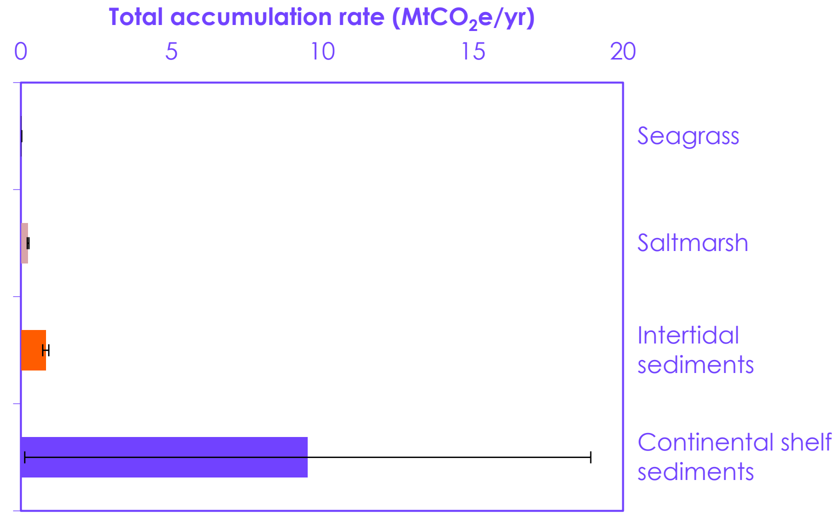
Figure 2.1 Carbon accumulation measured in marine and coastal ecosystems, per unit area



Source: Parker et al. (2021) *Blue Carbon stocks and accumulation analysis for Secretary of State (SoS) region*; Novak et al. (2020) *Factors Influencing Carbon Stocks and Accumulation Rates in Eelgrass Meadows Across New England, USA*; Arias Ortiz (2019) *Carbon Sequestration Rates in Blue Carbon Ecosystems: a perspective on climate change mitigation;* Ouyang and Lee (2014) *Updated estimates of carbon accumulation rates in coastal marsh sediments;* Duarte et al. (2005) *Major role of marine vegetation on the oceanic carbon cycle*; Wilkinson et al. (2018) *A synthesis of modern organic carbon accumulation rates in coastal and aquatic inland ecosystems.*

Notes: Diamonds and coloured bars represent data measured in UK EEZ - compiled by Parker et al. (2021) - except for seagrass. Triangles represent global average values for saltmarsh, seagrass, intertidal sediments and the continental shelf. For seagrass, no available UK-specific values. In figure 2.1, points represent most applicable international measurement, as outlined in Parker et al. (2021). Data does not include the UK's continental slope and deep-sea muds.

Figure 2.2 Total carbon accumulation in UK marine and coastal ecosystems



Source: Source: Parker et al. (2021) Blue Carbon stocks and accumulation analysis for Secretary of State (SoS) region; Novak et al. (2020) Factors Influencing Carbon Stocks and Accumulation Rates in Eelgrass Meadows Across New England, USA; Arias Ortiz (2019) Carbon Sequestration Rates in Blue Carbon Ecosystems: a perspective on climate change mitigation; Ouyang and Lee (2014) Updated estimates of carbon accumulation rates in coastal marsh sediments; Duarte et al. (2005) Major role of marine vegetation on the oceanic carbon cycle; Wilkinson et al. (2018) A synthesis of modern organic carbon accumulation rates in coastal and aquatic inland ecosystems.
Notes: Values from Parker et al. (2021), calculated by multiplying mean or best estimate accumulation rates in figure 2.1 by habitat extent. For seagrass, no available UK-specific values. Data does not include the UK's continental slope and deep-sea muds.

Saltmarsh and seagrass: abatement potential

Carbon fluxes and stores in saltmarshes and seagrass meadows are amenable to management, reflected in their **status as blue carbon ecosystems**. Soils in these ecosystems currently store significant quantities of organic carbon, equivalent to around 17% of the UK's total annual emissions in 2020.[33, 34] Therefore, degradation of saltmarsh and seagrass soils has the potential to release carbon to the atmosphere,[35] and protection of existing ecosystems is important.

Restoration of saltmarsh and seagrass ecosystems can support GHG mitigation by protecting existing carbon stores and increasing carbon accumulation.

Habitat restoration may also contribute to GHG mitigation. As historic habitat loss has occurred in both ecosystems,[36, 37] there is potential to restore saltmarsh and seagrass habitat extent and increase carbon sequestration and storage.[38,39] In England, the Restoring Meadow, Marsh and Reef (ReMeMaRe) project aims to restore 15% of three of England's priority coastal habitats (saltmarsh, seagrass and native oyster beds) by 2043. [40] Applying this target to whole UK areas, and using the average accumulation rates from across restored and natural systems given above,[41] it is estimated that:

- An additional 72 km^2 of saltmarsh habitat would result in additional carbon accumulation of 0.04 $MtCO_2e/yr$, while an additional 11 km^2 of seagrass meadow would result in additional accumulation of 0.003 $MtCO_2e/yr$.

- More ambitious habitat restoration targets have been suggested, which may result in additional carbon accumulation. For instance:

- One study suggests that 220 km^2 of saltmarsh habitat could reasonably be created.[42] Once established, this would result in additional carbon accumulation of around 0.1 $MtCO_2e$/yr.

In addition to the significant uncertainties regarding geographic variability in accumulation rates, estimates of GHG mitigation from UK restoration projects should ensure the timescale of calculated mitigation benefits is made clear:

- Rates of carbon accumulation vary with time after restoration. Data from UK saltmarshes suggest that carbon accumulation is initially fast, before slowing to a steady rate after around 20 years.[43]

- Conversely, it has been demonstrated that carbon accumulation rates in US seagrass meadows increased with time after restoration.[44]

More accurate estimates of the net change in GHG fluxes associated with habitat management would also need to consider:

- The relative contribution of carbon derived from within and outside of these ecosystems.[45]

- Emissions of other greenhouse gases during habitat management, including methane[46,47] and nitrous oxide[48] to determine if they are significant in the overall GHG budget.

- Land use prior to habitat creation or restoration.

With regards inclusion in the UK's GHG inventory, the IPCC Wetlands Supplement includes methods to account for these complexities, where they are relevant. Approaches which aim to facilitate the use of blue carbon habitat management in carbon offsetting contexts (e.g., the UK's saltmarsh carbon code, which is currently under development[49]) should also consider these.

Nationally, GHG abatement by saltmarsh and seagrass meadows is relatively small but may provide extremely efficient carbon removal at local scales.

Despite considerable uncertainties, the estimates presented here are likely valid as order of magnitude approximations, and agree with previous studies.[50,51] **Restoration and creation of saltmarsh and seagrass habitat is likely to yield additional GHG abatement of less than 1 MtCO2e/yr.** However, individual restoration projects may provide extremely efficient carbon removal at a local or regional scale.[52] Protection of these ecosystems and their carbon stores is important for avoiding additional GHG emissions.

Carbon cycling in other marine and coastal ecosystems outside of saltmarsh and seagrass is less well understood.

Carbon cycling in other marine and coastal ecosystems, such as marine sediments (intertidal and subtidal)*, kelp, sand dunes and machair, and carbonate-forming ecosystems, is less well understood. There is limited evidence on how management activities influence carbon stores and fluxes in these ecosystems. Although they cannot currently be included in the UK's GHG Inventory, there may be other national policy opportunities to support their protection.

Marine sediments

Carbon in marine sediments accounts for most of the carbon stored in the UK's marine and coastal ecosystems.

Carbon in marine sediments accounts for the majority of overall current carbon storage in the UK's marine and coastal ecosystems (Figure 1.2), mainly due to their substantial areal extent.[53,54] The carbon which accumulates in marine sediments can be derived from a diverse array of sources, and stores vary with factors including location, ocean conditions and sediment type. For instance, finer sediments (muds) tend to have higher carbon contents than coarser, sandy sediments.[55] Overall, this variability makes estimating the total magnitude of the UK's marine sedimentary carbon stores difficult. Additionally, most data from UK marine sediments are measured to 10cm depth. To facilitate comparison with other ecosystems and studies, extrapolation to greater sediment depth may be necessary (e.g., 1m, as below).[56] Despite these uncertainties, UK marine sedimentary carbon stores are thought to be significant:

- The UK's local marine EEZ, including coastal sediments as well as those found in deeper waters on the continental shelf, continental slope and in deep sea ecosystems, is estimated to store up to 1900 (± 250) $MtCO_2e$ in the top 10 cm of marine sediments alone (Figure 1.2).[57]

- Assuming a uniform distribution of carbon with sediment depth,[58] this implies the top 1m of marine sediments in the UK's EEZ could store around 19000 $MtCO_2e$. While the uncertainties associated with such depth extrapolations must be emphasised, marine sediments store significant amounts of carbon. Fjord (or sea lochs and loughs), estuarine and coastal sediments are important carbon stores on a per area basis, due in part to their proximity to terrestrial carbon sources.[59]

Carbon accumulation rates in marine sediments are highly uncertain, and show pronounced variability (Figure 2.1):

- There are very few existing measurements of carbon accumulation rates in UK intertidal and subtidal ecosystems.[60]

- Carbon accumulation rates vary with proximity to land (Figure 2.1) and variability in the donor supply.[61]

- Additionally, some of the carbon which accumulates in marine sediments will be released back into the water column before entering long-term stores. The longevity of carbon in marine sediments depends on a range of factors including carbon composition (its "reactivity"), ocean conditions, disturbance, and sedimentation rates.[62, 63, 64]

* Intertidal sediments are located in the area between the mean low tide and mean high tide. Subtidal sediments are located below the low tide level and are submerged.

Carbon storage and accumulation in marine sediments is therefore controlled by a complex array of biological, chemical, and physical processes. It is currently difficult to quantify GHG emissions or sources associated with anthropogenic management activities:

- Activities which disturb marine sedimentary carbon stores – such as bottom trawling – can release a proportion of the carbon stored in sediments into the water column, where it may be oxidised to dissolved CO_2.[65, 66, 67, 68]

- Protecting vulnerable carbon stores in marine sediments from disturbance could therefore prevent degradation of marine sediment carbon stores.[69,70]

- However, the vulnerability of marine sediment carbon stores to disturbance, as well as the net effects of disturbance on both marine sediment carbon stores and, consequently, atmospheric GHG concentrations, are variable and difficult to quantify (Box 2).[71,72,73,74]

This uncertainty means it is currently difficult to effectively target policy interventions, and quantitively link these to GHG mitigation. However, protective measures could adopt a precautionary approach, and target sediments with high organic carbon contents (such as coastal and estuarine muds)[75], restricting damaging practices in these areas.

Kelp

Kelp forests sequester CO_2 by photosynthesis. This carbon may then be transported and stored long term in other ecosystems.

Kelp is a type of macroalgae which sequesters CO_2 by photosynthesis, forming 'forests' on hard, rocky substrates around the UK coastline. This rocky habitat generally limits in-situ carbon accumulation. However, a proportion of kelp biomass will detach from the rock and may be transported and "donated" to long-term storage in other ecosystems, including marine sediments.[76]

- It is estimated that kelp biomass in the UK contains organic carbon equivalent to around 14 $MtCO_2e$[77] (Figure 1.1).

- However, the proportion of kelp biomass which enters long-term storage is highly uncertain. One study on the south coast of the UK found this proportion was around 4 to 9%,[78] noting this is likely to vary substantially with local factors including ocean conditions and circulation patterns.[79, 80]

- Additionally, it has recently been suggested that kelp forests may be a net source of CO_2, when interactions with the wider ecosystem are considered.[81] Links between kelp and GHG mitigation are complex and, currently, uncertain.

The role of kelp and seaweeds more broadly in climate mitigation includes the applications of seaweed aquaculture, which can be used to produce biofuel and improve soil quality when used in place of synthetic fertilizer.[82] Other applications of seaweed aquaculture include production of food, animal feed and medicines.[83, 84]

Sand dunes and machair

Sand dunes and machair have received less attention than other coastal ecosystems but potentially hold important stores of carbon in their soils.

Other coastal habitats including sand dunes (formed when sand blown from beaches is stabilised by vegetation) and machair (a type of grassland which develops in shelly sands, found in Scotland and Ireland) have received comparatively little attention, but are thought to hold important stores of carbon in their soils:[85,86]

- UK sand dune soils (15cm depth) are estimated to store around 6 $MtCO_2e$.[87]
- Machair soils (15cm depth) are estimated to store around 2 $MtCO_2e$.[88]

Sand dune and machair habitats are not routinely considered in studies of marine and coastal carbon. We have only identified one study which measures carbon stores in these ecosystems,[89] and carbon accumulation rates are very poorly studied.[90] Protection and restoration of these ecosystems will likely have mitigation benefits, however more evidence is required to quantify these.

Carbonate-forming ecosystems

Organisms combine calcium and carbonate to form hard shells and skeletons out of the mineral calcium carbonate.

Carbonate-forming ecosystems include bivalve (e.g., oysters, mussels, and scallops), cold-water coral and maerl reefs. They are not typically considered blue carbon habitats or relevant to GHG mitigation,[91] because the process of calcification releases CO_2.[92] However maerl – a form of calcifying seaweed – does sequester carbon during photosynthesis and by trapping transported carbon.[93] However, more evidence is required to quantify the relative balance between CO_2 accumulation during burial and release during calcification. [94] While it has been suggested that maerl beds represent stores of blue carbon[95] further investigation is required before they can be considered in a mitigation context.

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Chapter 3

Marine and coastal ecosystems in the GHG inventory

The UK's GHG inventory reflects emissions sources or sinks which are demonstrably associated with specific anthropogenic management activities. In this chapter we assess whether management activities associated with the UK's marine and coastal ecosystems can be included in the GHG inventory and where evidence gaps prevent from doing so.

1. Natural ecosystems in the UK GHG Inventory

Effective management of marine and coastal ecosystems may provide mitigation benefits.

Activities which impact the capacity of marine and coastal ecosystems to store and accumulate organic carbon will have implications for the UK's GHG emissions. For instance, their effective management may provide mitigation benefits, by enhancing carbon sequestration and protecting carbon stores to avoid emissions. Conversely, damage to these ecosystems risks degrading carbon stores, with associated increases in GHG emissions. **Carbon in marine and coastal ecosystems is not currently included in the UK's GHG inventory**, leading to concerns that the UK's inventory may be excluding a large emissions source or sink.

Separating natural and anthropogenic processes is difficult in marine and coastal ecosystems.

The UK's GHG inventory is concerned with emissions sources or sinks which are demonstrably associated with specific anthropogenic management activities (Box 1). However, the division between managed and natural ecosystems is not straightforward. Many existing coastal ecosystems are influenced by past or present land use changes, or indirectly affected by anthropogenic activities (e.g., nutrient loading from coastal development).

The managed land proxy assumes that, if land is managed, anthropogenic fluxes dominate.

Classifying whether existing coastal ecosystems are "natural" or "managed" may not, therefore, be practical. Instead, the **'managed land proxy'** can be used which assumes that all existing coastal ecosystems are to some degree "managed" and are therefore included in the inventory. This approach has been used to facilitate the inclusion of saltmarshes in the US GHG inventory.[1]

More broadly, the UK's GHG inventory was designed to account for point sources of emissions or removals on land. Terrestrial, coastal and marine ecosystems are linked by complex biological and fluvial processes, creating significant challenges for emissions accounting (Box 1). The connectivity of these systems is not well-suited to the siloed nature of the inventory and addressing evidence gaps with regards carbon provenance and transport between different systems is a priority for future work.

Saltmarsh and seagrass

The IPCC Wetlands Supplement contains guidelines for including management of saltmarshes and seagrass in national GHG inventories.

The IPCC Wetlands Supplement[2] contains guidelines for including management of saltmarshes and seagrass meadows in national GHG inventories and identifies management activities which can result in changes in GHG emissions. In a UK context, these include extraction (e.g., excavation to allow development), drainage and habitat creation or restoration. There is also scope to include additional management activities which go beyond those identified by the IPCC if evidence is sufficient to do so. For instance, the US GHG inventory includes emissions associated with the conversion of saltmarsh to an open water system, due to subsidence associated with anthropogenic activities.[3]

There is basis for inclusion of saltmarsh and seagrass in the UK GHG inventory.

Therefore, **there is basis for inclusion of saltmarsh and seagrass** in the UK GHG inventory (Table 1). The minimum requirement for reporting is knowledge of the extent of saltmarshes and seagrass meadows, and annual reporting of areas subjected to defined management activities:

- For UK saltmarshes, much of this information exists, but is not routinely collated in an easily accessible manner. This is a logistical exercise, and tools exist to address this problem.[4]
- For seagrasses, the first detailed assessment of UK habitat extent was published in 2021.[5] Routine monitoring presents a greater challenge than for saltmarshes.

The initial approach to GHG reporting (IPCC Tier 1 methodology in the Wetlands supplement) involves multiplying changes in habitat extent by default emissions factors provided in the Wetlands supplement.[6] However, these default values may not be appropriate for UK habitats (Figure 2.1). More robust estimates (IPCC Tiers 2 and 3) require UK specific emissions factors to be developed:

- For saltmarsh, this would require improved spatial and temporal coverage of carbon stock measurements and – particularly – accumulation rates. The UKRI C-side project is currently working to address this evidence gap.[7]
- Evidence gaps are again more extensive for seagrass ecosystems: there is limited UK data on carbon stores, and no measurements of UK-specific carbon accumulation rates.

There is basis for the inclusion of saltmarsh and seagrass in the UK GHG inventory. Saltmarsh currently represents the best candidate for inventory inclusion, with a larger relevant evidence base and better constraint on carbon accumulation and storage.[8] Therefore, we recommend:

- **R1: BEIS should produce a roadmap to inclusion of saltmarsh and seagrass in the GHG inventory, which specifies a suggested level of inclusion (i.e. Tier 1, 2 or 3), the additional data required to facilitate this and an indicative timescale to inclusion.**

Other marine and coastal ecosystems

IPCC guidelines do not currently exist for other UK relevant marine and coastal ecosystems beyond saltmarsh and seagrass.

Carbon cycling in other marine and coastal ecosystems is less well understood. Indeed, no IPCC guidelines exist for reporting emissions associated with other UK relevant marine and coastal ecosystems beyond saltmarsh and seagrass. Despite this, the UK has the option to include specified management activities which cause major anthropogenic GHG sources or sinks, provided sufficient evidence exists to do so and robust reporting procedures can be demonstrated.[9,10] Additionally, if sufficient evidence suggests that ecosystem management interventions could protect carbon stores and/or enhance carbon accumulation, these should be implemented regardless of the status of inventory inclusion.

As outlined in Section 2 and Box 2, scientific uncertainties mean that management activities (e.g., bottom trawling – see Box 2) associated with other marine and coastal ecosystems, including marine sediments and kelp, cannot currently be included in the UK's GHG inventory. Furthermore, there are practical difficulties associated with including marine ecosystems in the inventory, relating to scope and attribution:

- The UK's inventory currently covers land extending to the mean high-water mark, meaning the scope of the inventory would require significant expansion to include marine habitats (note the Wetlands Supplement sets a useful precedent and outlines solutions for the inclusion of saltmarsh and seagrass habitats).

- The transport of carbon from donor habitats (such as kelp) to storage habitats (such as marine sediments) creates accounting challenges which must be overcome by robust evidence and reporting procedures. Transport can also occur across national boundaries, creating attribution difficulties.

Therefore, scientific uncertainties mean that management activities associated with other marine and coastal ecosystems cannot currently be included in the UK's GHG inventory. However, this situation is likely to change in the future as more evidence becomes available.

Box 2
Case study: Accounting for emissions from disturbing marine sediments

Disturbance of marine sediments can occur through anthropogenic activities including **bottom trawling** – a process by which fish are caught by dragging a net along the seabed disturbing the top layer of marine sediment. This releases a proportion of carbon stored in sediments into the water column, where some of that carbon may be oxidised to dissolved CO_2.[11,12,13]

However, the amount of carbon released from sediments to the water column during trawling is uncertain due to a range of factors:

- The amount of sediment and carbon disturbed depends on factors including sediment type[14] and the type of trawling gear being used.[15]
- Only some of the disturbed carbon is susceptible to oxidation (loss). This proportion depends on factors including the reactivity of the carbon disturbed, and water column conditions. [16,17,18]
- The net effect of disturbance on sedimentary carbon stores will also be affected by the release of nutrients which may stimulate productivity in the surface ocean, and effects on organisms living in the sediments before and after disturbance.[19]

Additionally, the effect of sediment disturbance on atmospheric CO_2 concentrations has not been quantitatively estimated:

- Emissions of CO_2 to the water column could influence atmospheric CO_2 concentrations in two ways:
  - **Direct release of CO_2 from the ocean to the atmosphere** could occur if the water containing the additional dissolved CO_2 reaches the surface ocean and has time to equilibrate with the atmosphere. This is dependent on local and regional ocean circulation patterns and may take thousands of years.[20] It is extremely difficult to accurately estimate how much of, and where, this carbon enters the atmosphere.
  - **By affecting the ability of the ocean to absorb atmospheric CO_2.** The ocean has historically absorbed more than a quarter of anthropogenic CO_2 emissions.[21] If sediment disturbance increases oceanic CO_2 concentrations, the capacity of the ocean to absorb atmospheric CO_2 may reduce. However, these effects have not been quantified.

Therefore, while disturbance of marine sedimentary carbon stores may have implications for the UK's GHG emissions, fundamental scientific uncertainties currently prevent accurate quantification of this effect. Inclusion in the UK's inventory will require significant progress in reducing scientific uncertainties and developing robust reporting procedures.

Source: A full list of the sources can be found within this chapter's endnotes.

Table 1
Summary of carbon accumulation and storage in blue carbon habitats*

	Saltmarsh	Seagrass
Ecosystem description	Vegetated, coastal habitat which is periodically flooded at high tide.	Aquatic plants which form submerged meadows in shallow marine ecosystems.
Role in carbon cycling	Sequestration: vegetation sequesters CO_2, trapping and burial of allochthonous carbon. Storage: in-situ in soils.	Sequestration: vegetation sequesters CO_2, trapping and burial of allochthonous carbon. Storage: in-situ in soils.
Area extent within the UK's EEZ (km^2)	440 – 470	70 – 90
Carbon accumulation rates per unit area ($gC/m^2/yr$).	UK range: 66 – 195.5 UK average: 136 (± 15) (n = 7)	No UK data - representative value: 86 (± 19) Global average: 24 (± 6)
Carbon stores per unit area, to 1m soil depth (kgC/m^2)	Range: 10.1 – 69.0 Average: 36.8 (± 0.5) (n = 72)	Range: 4.6 – 38.0 Average: 13.0 (± 0.1) (n = 21)
Estimated total carbon stores in UK EEZ ($MtCO_2e$)	~ 65 (1m depth)	~ 3 (1m depth)
Estimated total carbon accumulation in UK EEZ ($MtCO_2e/yr$)	~ 0.2	~ 0.02
Additional carbon accumulation from 15 % UK-wide habitat restoration by 2043 ($MtCO_2e/yr$)	0.04† (additional ~ 70km^2 saltmarsh habitat)	0.003‡ (additional ~ 11 km^2 seagrass habitat)
Confidence rating and key areas of uncertainty	**Medium confidence** • Habitat extent (current and potential). • Geographic variability in stores and accumulation. • Temporal variability in accumulation rates. • Differences in carbon cycling response to management, particularly between natural and restored saltmarsh. • Inconsistency in depth measurements.	**Very low confidence** • Habitat extent (current and potential. • Limited UK studies for carbon stores (n=3) and no UK studies for accumulation (estimate based on 11 sites in the US, which may not be representative of UK ecosystems[1]). • Geographic variability in stores. • Inconsistency in depth measurements.
Risks to ecosystem and carbon stores	• Extraction for port/harbour maintenance and creation.	• Nutrient and sediment run-off from land.

* Estimates of carbon storage and accumulation presented here represent both natural and anthropogenic processes.

† Calculated by multiplying central estimates of carbon accumulation rates1 by additional area gained from restoration of 15 % of current areal extents. 15 % target based on England's national target but here is applied to whole-UK area to illustrate potential mitigation benefits of a whole-UK approach.

‡ See above footnote.

	• Coastal squeeze due to rising sea levels. • Change in land-use for coastal development or agricultural purposes	• Disturbance by trawling and anchoring. • Increased prevalence of low oxygen levels.
Do IPCC guidelines for inventory inclusion exist?[7]	IPCC guidelines: Yes	IPCC guidelines: Yes
Is the ecosystem currently included in the UK's GHG inventory?	Included: No	Included: No
Key evidence gaps to inventory inclusion	Improved temporal monitoring of changes in habitat extent and condition required. Improved constraint on soil carbon accumulation rates and stores required.	Temporal monitoring of habitat extent not routinely carried out. Improved constraint on soil carbon stores required. Currently no UK-specific measurements of carbon accumulation.

Source: Parker et al. (2021) *Blue Carbon stocks and accumulation analysis for Secretary of State (SoS) region*; Burden et al. (2020) *Impacts of climate change on coastal habitats, relevant to the coastal and marine environment around the UK*; Green et al. (2021) *Historical Analysis Exposes Catastrophic Seagrass Loss for the United Kingdom*; Arias Ortiz (2019) *Carbon Sequestration Rates in Blue Carbon Ecosystems: a perspective on climate change mitigation*; Novak et al. (2020) *Factors Influencing Carbon Stocks and Accumulation Rates in Eelgrass Meadows Across New England, USA*; ReMeMaRe project, https://ecsa.international/reach/restoring-meadow-marsh-and-reef-rememare; IPCC (2014) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.*

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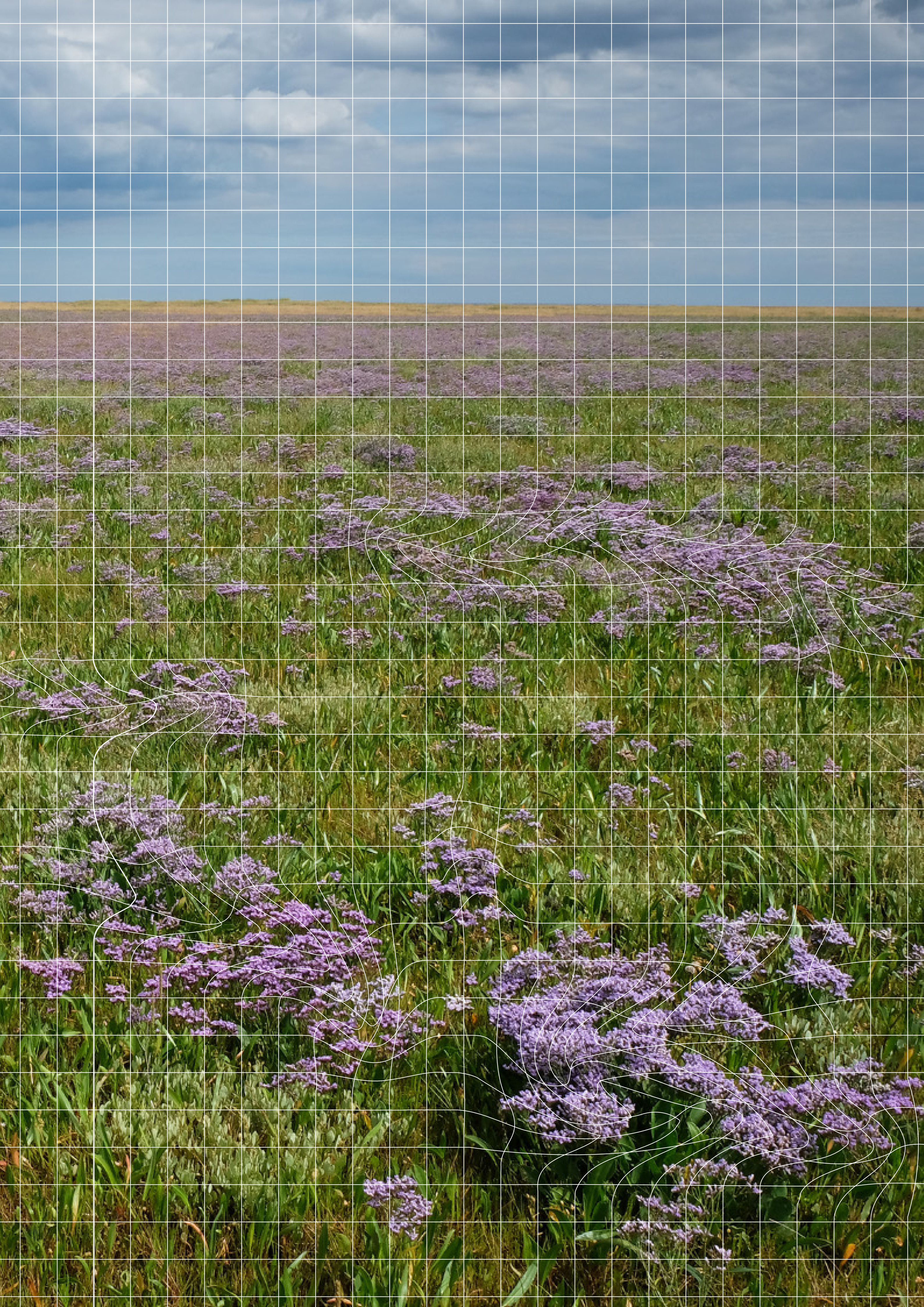
Chapter 4

Co-benefits, risks and management

In this chapter we consider the role of marine and coastal ecosystems in addition to their contribution to climate change mitigation. Biodiversity, climate resilience and other benefits provide a strong case for their effective management.



1. Co-benefits

Marine and coastal ecosystems provide important services relating to coastal flood risk management and wider environmental and economic benefits.

In addition to their carbon sequestration and storage value, marine and coastal ecosystems provide important services relating to coastal flood risk management and wider environmental and economic benefits:

- **Flood risk management:** Saltmarshes are recognised as a nature-based solution to flood risk in the National Flood and Coastal Risk Management Strategy for England.[1] Modelling suggests the economic benefits derived from their flood protection value may exceed those of carbon storage.[2] Seagrass meadows are known to stabilise sediments and limit coastal erosion,[3] while large kelp forests may also reduce wave energy.[4]

- **Biodiversity:** Marine and coastal ecosystems support habitats rich in biodiversity. Saltmarshes provide breeding grounds for a range of bird species,[5] while seagrass is recognised as a foundational species, supporting a range of fish, wildfowl, and shellfish.[6, 7] Additionally, kelp forests provide the foundations for marine food webs,[8] while carbonate reefs support a wide range of biodiversity.

- **Fisheries:** Habitats including seagrass meadows, kelp forests and maerl beds provide nursery grounds for commercial fish species, and more broadly fishing practices both influence and depend on the health of marine and coastal ecosystems.[9, 10, 11, 12]

- **Tourism:** A range of marine and coastal ecosystems provide significant economic benefits to local communities by encouraging nature-based tourism.[13, 14]

- **Water quality:** Saltmarshes trap sediment and filter pollutant phases, improving local water quality.[15] In turn, this benefits local biodiversity, fisheries support and tourism.

2. Risks to marine and coastal ecosystems

Marine and coastal ecosystems are at risk from damaging activities on the land, coast and at sea.

Marine and coastal ecosystems face a complex mix of direct and indirect pressures. Understanding the nature of these risks, the associated changes in ecosystem health and implications for marine and coastal biodiversity and carbon cycling is an important research priority:

- Activities including drainage, dredging, and trawling cause direct, physical damage to marine and coastal ecosystems, and have resulted in significant historic habitat loss and degradation.[16, 17]
- The health and extent of marine and coastal ecosystems is linked to management on land. Kelp, saltmarsh, maerl and seagrass ecosystems are known to be sensitive to nutrient loading which can be caused by runoff from agricultural land, or effluent outflows. [18,19, 20, 21, 22,]
- Coastal developments can cause increased sediment runoff into coastal and marine ecosystems, increasing turbidity and reducing penetration of light into the water column. This has negative impacts on ecosystems which rely on photosynthesis, including seagrass[23, 24, 25] and kelp.[26, 27]

Future climate change will impact the health and function of marine and coastal ecosystems.

These ecosystems also **face risks from climate change**. Rising sea-levels, increasing ocean temperatures, increased prevalence of low oxygen levels and ocean acidification are all signatures of anthropogenic climate change which will increasingly impact marine and coastal ecosystems in the future. The CCC has published an extensive review of these risks in our most recent Climate Change Risk Assessment.[28] These include:

- Rising sea-levels threaten coastal ecosystems such as saltmarshes, which may become "squeezed" between rising water levels and flood defence structures.[29, 30]
- Warmer ocean temperatures[31] are likely to drive changes in species distributions,[32] and may be detrimental to the integrity of ecosystems such as kelp forests[33] with risks to the carbon held in these habitats.
- Low oxygen levels will become increasingly prevalent in the future,[34] with potentially severe, negative implications for shallow-water ecosystems.[35]
- Ocean acidification will have negative impacts on the UK's carbonate-forming ecosystems.[36]

Changes in ecosystem health, functioning or composition induced by anthropogenic pressures including climate change will have complex implications for marine and coastal carbon stores and fluxes. For instance, while carbon burial in maerl reefs may increase with rises in ocean temperatures, this may also result in in ecosystem reorganisation – while carbon burial may also be affected by changes in land use, carbonate chemistry and oxygen levels.[37]

Given the importance of marine and coastal ecosystems in the wider contexts of biodiversity, fisheries, and global carbon cycling, understanding current and future trends in their health, composition and functioning should be addressed by future research. Therefore, our second recommendation is that:

- **R2: Efforts to monitor, understand and analyse changes in the extent, condition and functioning of marine and coastal ecosystems should be encouraged, including an assessment of the risks these present to emissions and wider ecosystem value and with reference to the changing climate and other pressures.**

3. Ecosystem management: Building resilience

Management interventions can build resilience and restore the health of marine and coastal ecosystems.

Improved understanding of the resilience of marine and coastal ecosystems to the risks outlined above will help the design and implementation of effective management interventions. Holistic management approaches, which account for the intrinsic links between different terrestrial and marine ecosystems, will be required to build resilience and restore the health of marine and coastal ecosystems. Additionally, successful management should include engagement with and consideration of the communities and economic sectors these ecosystems support.

Protection of many marine and coastal ecosystems is facilitated by the UK's network of Marine Protected Areas (MPAs). For instance, around 40% of UK Secretary of State waters* fall within the MPA network. However, it is widely recognised that the protection this affords is insufficient to allow ecosystems to recover fully.[38] This may result from the fact that many MPAs protect specific habitats or species, allowing extraction to continue elsewhere in the local environment.[39] The UK government is currently selecting five Highly Protected Marine Areas (HPMAs) to trial greater levels of protection, taking a "whole-site" approach to protection. These sites are due to be selected in 2022, and selection will include consideration of the value of carbon stores and fluxes.[40]

More broadly, enforcement of the protections provided by the UK's MPA network needs to be strengthened. This is recognised by the UK government, whose response to this issue being raised in the CCC's 2021 Adaptation Progress Report[41] was: "38% of UK waters (are included) in Marine Protected Areas…Government's focus is now on ensuring these are effectively protected."[42] Therefore, we recommend that:

- **R3: The UK government and devolved administrations should continue to strengthen protection and restoration in marine areas, and support efforts to manage marine and coastal ecosystems sustainably, giving due consideration to their carbon value.**

Saltmarsh management is recognised as an effective nature-based solution to coastal flood risk management, including in the most recent National Flood and Coastal Risk Management Strategy for England.[43] This recognition has provided impetus and funding for restoration projects. However, for other marine and coastal ecosystems, management activities are sporadic and ad-hoc.[44, 45] Funding mechanisms that recognise the wider benefits of these habitats should be available to support restoration and management, while in the future carbon offsets approaches could fund efforts, once those benefits have been robustly quantified.

Marine and coastal ecosystems should be considered as part of wider catchments.

It is also clear that marine and coastal ecosystems should be considered as part of broader efforts to manage catchments which span terrestrial, coastal and marine ecosystems. Many of the risks to marine and coastal ecosystems, such as sediment and nutrient run-off, can only be mitigated by making land-based interventions, and catchment-based approaches should be at the heart of restoration and protection efforts.[46, 47, 48]

* Secretary of State waters are English territorial waters and UK offshore waters around England, Wales and Northern Ireland.

Replacement of the Common Agricultural Policy (CAP) with other schemes is ongoing, presenting the opportunity to make explicit reference and consideration to marine and coastal ecosystems in these schemes, delivering wider benefits beyond terrestrial land management.

Wider policy levers can also provide an opportunity to manage these ecosystems. An example of an effective intervention is the successful leveraging of the planning system in the Solent, where the nutrient neutrality principle has ensured that new developments do not increase nutrient burdens on fluvial and coastal ecosystems. A siloed approach which considers the marine ecosystems in isolation is unlikely to succeed in restoring or protecting many of these ecosystems, and our final recommendation is that:

- **R4: The interaction of marine and coastal ecosystems with wider catchments should be recognised in the design of initiatives to replace the Common Agricultural Policy, and opportunities for use of wider policy levers to deliver better management should be pursued.**

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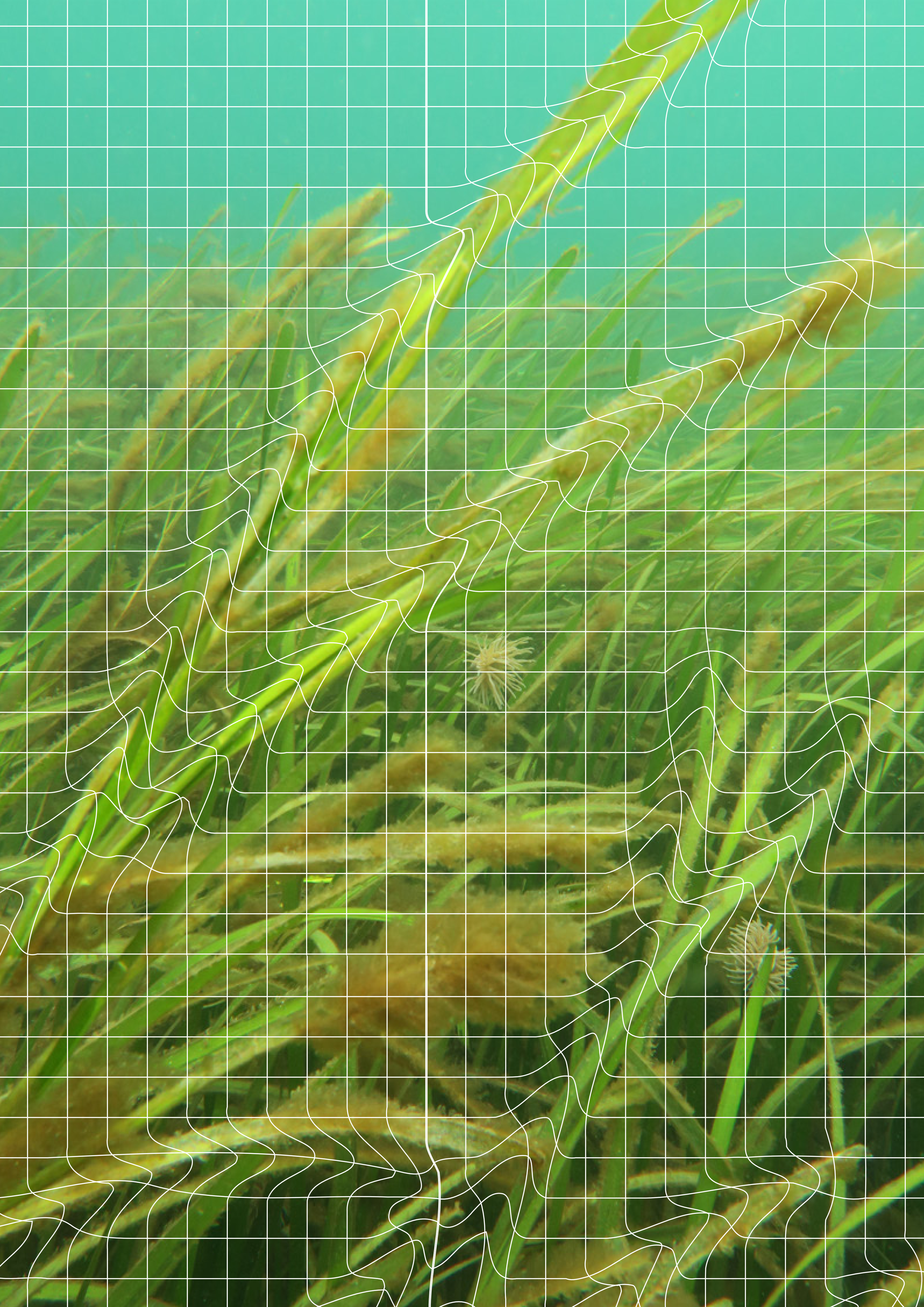
Chapter 5

Summary and recommendations



1. Recommendations

Marine and coastal ecosystems have implications for UK greenhouse gas emissions. Our understanding of carbon emissions, storage and accumulation in these systems, and its links to GHG mitigation, are better for some ecosystems than others:

Saltmarsh and seagrass can contribute to GHG mitigation, though will have minor implications for the UK GHG inventory.

- Carbon accumulation, storage and emissions are best understood in saltmarsh and seagrass. These will have minor implications for the UK's GHG inventory but could make a small contribution to GHG mitigation: restoration provides mitigation benefits, while continued habitat loss will result in emissions.

- Due to their extent, larger amounts of carbon are sequestered by and stored in marine sediments, and carbon "donor" ecosystems, such as kelp. These ecosystems are more poorly understood, and the nature of this carbon is currently harder to quantify and manage in the context of GHG mitigation.

Marine and carbon ecosystems should be protected and managed to support their delivery of a wide array of co-benefits.

In addition to their carbon value, these ecosystems deliver a wide array of co-benefits. Effective management of these ecosystems is critical to protect and enhance these benefits, and to build resilience to the numerous and severe risks these ecosystems face from climate change. Considering the available evidence, and in discussion with a range of stakeholders, we make four specific recommendations:

- **R1: BEIS should produce a roadmap to inclusion of saltmarsh and seagrass in the GHG inventory, which specifies a suggested level of inclusion (i.e. Tier 1, 2 or 3), the additional data required to facilitate this and an indicative timescale to inclusion.**

  - Saltmarsh is currently the best candidate for inventory inclusion and should be prioritised.

  - The timescale to inclusion of saltmarsh in the inventory should depend on the targeted Tier of inclusion. Given existing evidence, we suggest that Tier 1 inclusion should be achieved within the next 2 years. Higher Tier inclusion, requiring development of UK-specific emissions factors, should be achieved within the next 5 years.

  - IPCC guidelines[1] also exist for seagrass ecosystems, but the UK evidence-base is less developed. The roadmap should set out how key data gaps, which currently inhibit data inclusion, will be addressed.

  - Roadmap development should include full consultation with Defra and with the academic and delivery sectors. The saltmarsh carbon code, which is currently under development,[2] provides a starting point for inventory inclusion.

- **R2: Efforts to monitor, understand and analyse changes in the extent, condition and functioning of marine and coastal ecosystems should be encouraged, including an assessment of the risks these present to emissions and wider ecosystem value and with reference to the changing climate and other pressures.**

  – Understanding the resilience and vulnerability of marine and coastal ecosystems to the effects of climate change and anthropogenic pressures remains a research priority.

  – Assessments should include consideration of risks to the intrinsic and economic value of these ecosystems, including implications for biodiversity, carbon cycling and emissions, and the range of sectors these ecosystems support, including fisheries.

  – Research should be used to inform decisions regarding the efficacy of management practices. Projects which manage marine and coastal ecosystems (see recommendation 3) could also be used to help facilitate data collection and evidence in this regard, focusing on the effects of management activities on carbon cycling, ecosystem resilience and other co-benefits.

- **R3: The UK government and devolved administrations should continue to strengthen protection and restoration in marine areas, and support efforts to manage marine and coastal ecosystems sustainably in the context of the changing climate, taking due consideration to their carbon value.**

  – The UK government and devolved administrations should continue to strengthen regulation of the UK's network of MPAs, and they should consider how policy levers – including legislation – could be more effectively and extensively employed in the marine realm to target damaging practices, such as bottom trawling.

  – The required transition to more sustainable management of the marine realm should be carried out in a just manner, with support provided to local communities and industries most affected by new measures.

  – Governments should consider whether good practise in marine and coastal management can be incentivised. For instance, it may be possible to emulate initiatives such as the Sustainable Farming Incentive[3] in a marine or fisheries context.

  – Governments should increase funding and support for projects – and project pilots – which aim to build the resilience of marine and coastal ecosystems to climate change through their protection and restoration.

  – Management of marine and coastal areas should aim to enhance carbon sequestration and storage. Protection could target areas with high rates of organic carbon accumulation and/or extensive organic carbon stores as well as areas where these stores are at risk.

- **R4: The interaction of marine and coastal ecosystems with wider catchments should be recognised in the design of initiatives to replace the Common Agricultural Policy, and opportunities for use of wider policy levers to deliver better management should be pursued.**

  - Marine and coastal ecosystems are linked to land management processes in the terrestrial realm, and effective management must consider this interconnectivity.

  - The replacement of the Common Agricultural Policy (CAP) presents an opportunity to improve management of coastal and marine ecosystems, and post-CAP schemes should include clear reference to this.

  - The planning system could be leveraged to require that new developments achieve nutrient neutrality, as has been demonstrated in the Solent.[4]

  - These considerations could also be used to address evidence gaps relating to the transfer of carbon between ecosystems within catchments, and how this is accounted for.

Endnotes

[1] IPCC (2014) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds), https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/

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