Marine Natural Capital Development on the Cumbrian Solway:

Current status, gaps and opportunities

Final report

Photo: saltmarsh at Bowness on Solway supplied by Solway Firth Partnership

Marine Natural Capital Development on the Cumbrian Solway:

Current status, gaps and opportunities

April 2022

Author(s): Beth Churn

Edited by: Emily Baxter and Clair McFarlan

Acknowledgements

The Marine Natural Capital Development on the Cumbrian Solway project was managed by Solway Firth Partnership and delivered by Cumbria Wildlife Trust. The project was funded by the Environment Agency's Championing Coastal Coordination fund and The Crown Estate. The project was possible thanks to contributions, advice and guidance from multiple individuals and organisations. With particular thanks to Clair McFarlan, Georgina Reid and Emily Baxter.

Executive Summary

The Solway Firth is a large and dynamic estuary that joins Dumfries and Galloway, in Scotland, to Cumbria, in England. Its vast and wild landscape is home to a mosaic of habitats, history and heritage. The coastal landscape has been characterised by a long history of agriculture, with large areas of traditionally-grazed saltmarsh. The saltmarshes, sand dunes, sand and mudflats support high levels of biodiversity including great numbers of internationally important bird species and commercially important fish and shellfish populations. This report describes a baseline assessment of the natural capital assets of the Cumbrian Solway Firth and reviews the potential opportunities for enhancing or restoring the ecosystem services provided by these assets to ensure the long-term provision of valuable benefits. Throughout the report, the Solway being referred to is the Cumbrian Solway, unless the Scottish side is specifically indicated.

On the English side of the Solway Firth, key natural capital assets include, saltmarshes, sand dunes and biogenic reefs. There are also vast areas of sublittoral sand and mud habitats. These assets provide valuable benefits from climate change mitigation through the sequestration and storage of carbon, to alleviating flood and erosion risk by stabilising sediments and attenuating wave and tidal energy. They also form habitats, increasing biodiversity and maintaining nursery populations of important fish and shellfish species. They play a role in regulating water quality and provide opportunities for wildlife watching, walking and other recreational activities that improve human wellbeing.

A large part of this project involved consultation with local stakeholders and other relevant projects and organisations around the UK. This was done through one-to-one meetings and an on-line stakeholder workshop. During the workshop it was recommended that the focus of this report, and future restoration efforts, should be on saltmarshes, sand dunes and water quality. Climate change mitigation, biodiversity enhancement and improved water quality were identified as the key beneficial ecosystem services provided by the Solway's natural capital assets and therefore should also be a focus for any natural capital projects.

The natural capital approach takes into consideration the value of the natural environment for society and the economy. To understand the value of natural capital assets, it is important to have knowledge of the spatial extent, condition and location of the assets as well as the different pressures that act on them. This information will help to inform priorities for restoration of key ecosystems, habitats or species populations.

The state of saltmarshes in the Solway was assessed as an example, using Natural England's natural capital logic chain. The location, extent and quality were reviewed using the best available data. The drivers of change and pressures were also outlined. The potential to improve the quality of the Solway's saltmarshes was then considered. They key findings from the logic chain are:

- The Solway's marshes are extensive and nationally important. They are well protected within multiple designated sites, meaning that there is relatively good information available on their condition.
- Saltmarshes contribute to the following beneficial ecosystem services: they play a key role in mitigating the impacts of climate change through carbon sequestration and storage; they stabilise sediment reducing the risk of coastal erosion; they reduce the risks from flooding by dissipating wave and tidal energy; they maintain nursery populations and habitats for important fish and shellfish species including European

smelt; they provide cultural services, including tourism and recreation and health and wellbeing; and they help to regulate coastal water quality.
- Overall, the saltmarsh is not in a state of erosion, it has been expanding in recent years but the extent should continue to be monitored.
- The Solway's saltmarshes are heavily grazed, to levels suitable for the wildfowl species that are important to the area. However, there is a general view from stakeholders that many of the marshes are overgrazed and reducing grazing levels may enhance the saltmarsh's diversity.
- The impacts of climate change, particularly sea level rise, is a key threat to the Solway's saltmarshes. Agricultural management including grazing regimes and nutrient run off were also identified as key pressures.
- From conversations with stakeholders, there are limited opportunities for inland habitat creation, or landward expansion, because of the natural topography of the coast and the relatively low levels of land reclamation.
- Further conversations between stakeholders should be held to discuss opportunities for saltmarsh expansion or enhancement in sites identified by the Cumbria Coastal Strategy.
- It will be most important and feasible to enhance the marshes that already exist through re-wetting and reducing grazing levels.

Through the research, consultation and stakeholder workshop, the following conclusions, data limitations and potential opportunities for further work have been identified.

Data gaps and deficiencies

In the Solway Firth, data on marine and coastal species and habitats is generally lacking compared to other regions of the UK. The following data gaps and deficiencies were identified:

- There is limited monitoring, or current data, on extent and condition of key habitats, such as blue mussels and honeycomb worm reefs.
- There is a lack of historical data and evidence of native oyster reefs or seagrass meadows.
- There has been a lack of consistent data collection and surveying effort for seagrass across the North West coast.
- There is a lack of evidence on the feasibility of restoring priority marine and coastal habitats, including blue mussel beds and honeycomb worm reefs.
- There has been little evidence and data collected to show that habitat enhancement work on sand dunes and saltmarsh in the Solway has increased the provision of beneficial ecosystem services. For example, changes in invertebrate, fish or bird biodiversity have not been recorded following previous enhancement work on the Solway's saltmarshes.

Recommendations

1. **Complete a full marine and coastal natural capital asset inventory for the Solway.** Building on the work outlined in the current report, there should be a more detailed review of the marine and coastal natural capital in the area that covers all species and habitats of importance, mapping of subtidal habitats and completing the list of the priority species that was started as part of the draft Local Nature Recovery Strategy (LNRS).

2. **Undertake further monitoring and data collection on the marine and coastal natural capital assets.** The Solway Firth remains largely understudied compared to other marine regions. Building up more data will help to inform the completion of a baseline assessment on the location, extent and quality of the natural capital assets.

3. **Produce logic chains for the Solway's key natural capital assets;** including sand dunes, biogenic reefs and other assets identified by the asset inventory. This work should include an assessment of the state of the assets.

4. **Increase the understanding of the ecosystem services provided by the Solway's natural capital assets.** Much of the information provided in this report is based on UK or Europe-wide studies and may not be true for the Solway. It may be possible to map and model the ecosystem services in the Solway (this has been done for the Blackwater Estuary, see Shapland et al., 2021), which would then inform priorities opportunities for enhancing ecosystem service provision.

5. **Improve understanding of the beneficiaries to the Solway's natural capital assets.** This initially can be done at a local/regional/national/international scale but with more data, more detailed work can be carried out to map which groups of people are seeing the benefits of the marine and coastal environment.

6. **Map the socio-economic uses of the Solway.** This would help to provide a picture of where natural capital restoration could take place while balancing the needs and priorities of different stakeholders. This would also assist in the understanding who the beneficiaries are.

7. **Research how the condition of the Solway's natural capital assets impacts their value.** For example, measure how differences in saltmarsh grazing regimes, (including sheep vs. cattle only grazing) impacts upon carbon storage, biodiversity or use of the saltmarsh as a nursery ground for fish.

8. **Collect empirical data on the carbon sequestration and storage rates of the Solway's saltmarshes** to better understand how this habitat is contributing to climate change mitigation and how it can be improved.

9. **Improve understanding of how European smelt and other juvenile fish use the Solway's saltmarsh.** The sampling strategy produced by Colclough et al. (2005) could be used and should look to identify any potential differences in habitat use in saltmarshes with varying grazing regimes.

10. **Continue to monitor accretion and erosion of the Solway's saltmarshes,** as well as changes in extent and the dynamics of associated sediment supply.

11. **Research potential methods for the restoration or enhancement of priority marine and coastal habitats,** including blue mussel beds and honeycomb worm reefs.

12. **Investigate potential habitat restoration sites.** Carry out further research and on-the-ground surveys of the sites recommended for habitat expansion or creation to see if they are suitable. Investigate sites that were shortlisted within the Dynamic Dunescapes and the Life on the Edge projects, as well as those identified in the projects discussed in this report.

13. **Research how local communities value marine and coastal natural capital assets.** The Scottish Wildlife Trust's Oceans of Value project and the Community Voices Method could be used to identify any hidden values.

In order for any future natural capital project to be successful, it is recommended the following steps are taken:

1. **Engage early** with communities, sea and coastal users, landowners, organisations and other stakeholders, to ensure success.
2. **Communicate what the natural capital approach is** with local communities, organisations and marine and coastal stakeholders, in order to overcome barriers such as, scepticism that the approach is all about money.
3. **Bring all saltmarsh landowners together** to share expertise and on-the-ground knowledge of the management of the marshes, discuss barriers to restoration and discuss the potential to change grazing levels.
4. **Involve local communities in any restoration work**. Through public engagement it will be important to increase awareness of the health and wellbeing benefits of saltmarshes and other marine and coastal ecosystems. This may help to realise the full potential of benefits derived from cultural services.
5. **Ensure monitoring and data collection** is conducted before, during and after any restoration work to help to inform whether it has been successful in increasing the value of the natural capital assets.
6. **Refer to best practice taking place in recent marine and coastal natural capital projects (or those with marine and coastal components) around the UK.** Examples include the:
    a. Blackwater Estuary Natural Capital Assessment
    b. Valuing the Solent Marine Sites, Habitats and Species
    c. Natural Capital Assessment of the Orkney Marine Region Area
    d. Natural Capital Evidence Compendium for Norfolk and Suffolk
    e. ReMEDIES: Natural Capital Seagrass and Mearl
    f. North Devon Marine Natural Capital Plan

Contents

1 Introduction and background

1.1 Overview

The Environment Agency's Championing Coastal Coordination Partnership Grants were established to support the testing and trialling of approaches that inform how to enhance and expand current arrangements for:

- Coordinated planning and delivery of locally owned plans and place-based initiatives through governance frameworks.
- Coastal champions to strengthen capacity and capability in local stewardship
- Strategic protection, restoration and recovery of natural habitats.

Similarly, The Crown Estate, an independent commercial business created by Act of Parliament that invests in and manages some of the UK's most important assets including the seabed and half the foreshore around England, Wales and Northern Ireland, was interested in investigating opportunities to:

- Explore the possibility of undertaking coastal habitat conservation and restoration on the Cumbrian side of the Solway to expand coastal, intertidal and marine habitats in support of climate mitigation and carbon sequestration.
- Gather new data and evidence.
- Raise awareness of the importance of natural capital amongst local communities.
- Increase skills and training opportunities within the local area.

The Solway Firth connects Dumfries and Galloway in Scotland with Cumbria in England. Due to the administrative differences between Scotland and England there are often additional complications that need to be overcome in order to achieve holistic action for the coastal environment across the border. The Solway Firth Partnership covers the whole of the Solway Firth, working across Dumfries and Galloway and across the Scottish Border, down to St Bees Head on the coast of West Cumbria (Figure 1).

Project Area

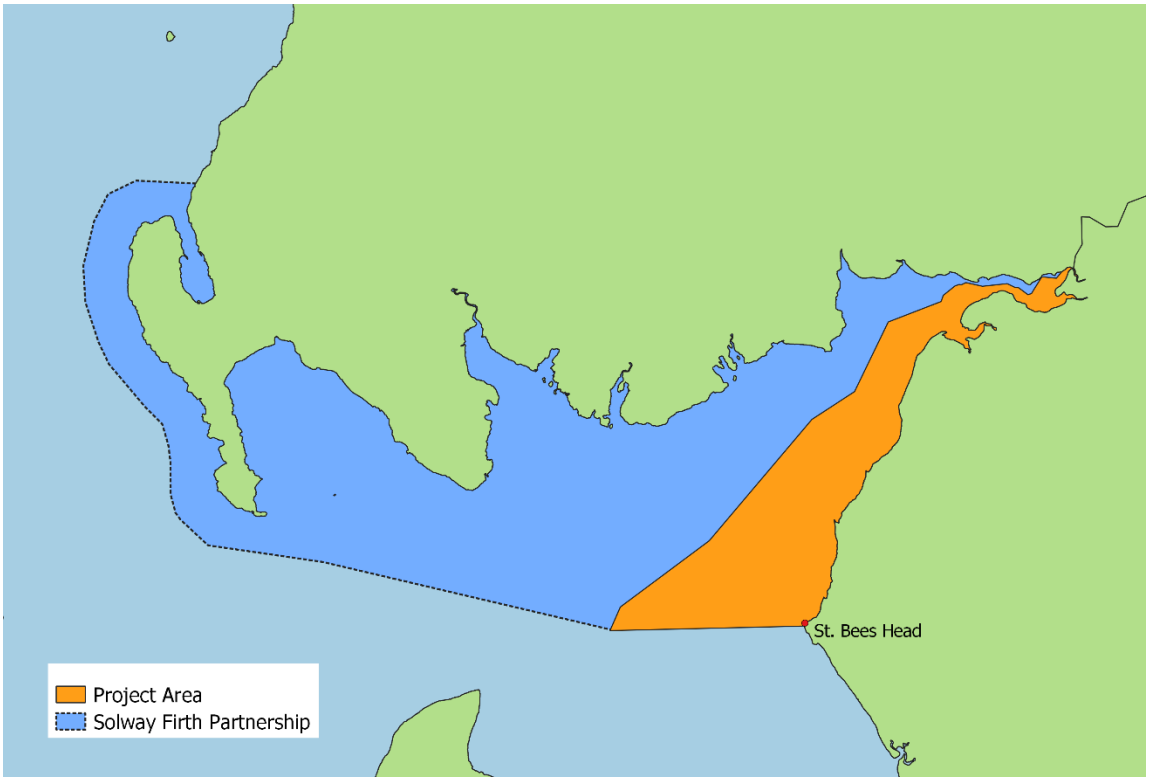

Figure 1 Project area and area covered by the Solway Firth Partnership

In early 2021, a project led by Solway Firth Partnership was established on the Scottish side of the Solway Firth, through funding from Borderlands Inclusive Growth Deal, to develop a pilot marine natural capital project. The Championing Coastal Coordination Partnership scheme, therefore, provided an opportunity to undertake complementary development work on the Cumbrian side of the Solway and ensure a holistic approach was taken by giving entire Solway due consideration. Working closely together, the projects were designed to explore possible future actions that could:

- Safeguard and restore the Solway's degraded natural capital assets. In particular: Saltmarsh restoration and expansion / shellfish reintroduction / seagrass conservation and reintroduction
- Maximise benefits from: Inclusive growth / social, health & wellbeing / climate change mitigation and carbon sequestration
- Develop and deploy practical restoration
- Increase skills and training opportunities
- Raise awareness of the importance of natural capital amongst local communities and the maritime economy
- Gather evidence for the creation of a methodology for a new Marine Carbon Code

The current project, Marine Natural Capital Development on the Cumbrian Solway, will help to form the basis of a delivery plan to achieve the nature recovery outcomes highlighted as part of the Draft Cumbria Local Nature Recovery Strategy (LNRS). The project was conducted between November 2021 and April 2022 with the following aims:

1. To undertake research on current academic and practical actions being undertaken relating to marine natural capital:

- Highlighting gaps and opportunities for Cumbria, focussing on added value and innovation
- Exploring the opportunities for restoration of marine natural capital habitats or species
- Preparing a baseline assessment utilising existing data, identify data gaps and deficiencies in currently available data
- Preparing supporting information for future work, focusing on added value and innovation

2. To engage all relevant stakeholders with an interest in marine natural capital on the Cumbrian coast:
    - Engaging key stakeholders with an interest in marine natural capital on the Cumbrian coast
    - Liaising with projects that have direct links to marine natural capital
    - Consulting government agencies, key industry, and private sector stakeholders

3. To produce a report detailing results from:
    - The desk-based research
    - The consultations with key stakeholders

This project covers the English side of the Solway Firth, working in the area from the Scottish Border at Gretna to St Bees Head (Figure 1).

This report presents a strategic assessment of the Cumbrian Solway's marine natural capital assets, and some of the potential opportunities for protection, enhancement, restoration or reintroduction of key assets. It draws together results from a review of academic and practical research related to marine and coastal natural capital, as well as from stakeholder consultation through one-to-one meetings and a collaborative workshop. It also reviews opportunities identified in the Cumbria Coastal Strategy, the Shoreline Management Plan refresh, the Environment Agency's ReMeMaRe[1] project and the Marine Management Organisation's Habitat Restoration Opportunity Mapping; bringing these together into a single resource. This project highlights some of the existing knowledge, as well as data gaps and deficiencies, and provides recommendations for future natural capital projects that could help to address some of the data gaps and provide innovative solutions to current environmental challenges.

1.2 The natural capital approach

1.2.1 What is natural capital

The natural environment underpins our social well-being and economic prosperity through the ecosystem services and benefits that it provides (Figure 2). However, the natural environment has been consistently undervalued during decision making.

[1] Restoring Meadow, Marsh and Reef (ReMeMaRe) is a habitat restoration initiative, aiming to address baseline shift and reverse the of decline of three of our priority estuarine and coastal habitats, seagrass meadows, saltmarshes and European native oyster (Ostrea edulis) reefs.

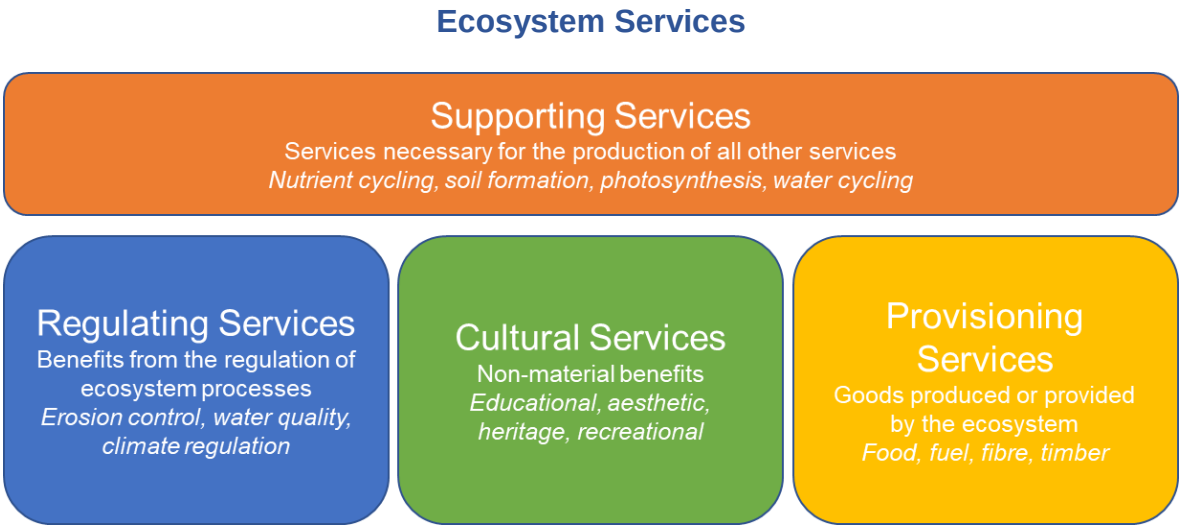

Figure 2 Description and examples of the different types of ecosystem services

Natural capital is an economic concept that aims to recognise the value of the natural environment to society. It refers to the natural and physical assets (habitats, species, air, water, soil etc.) from which ecosystem services flow, providing benefits to people. Natural England's logic chain illustrates how ecosystem services flow from natural capital assets to benefit people, generating value (Figure 3). The logic chain also shows how the state of natural capital affects the services and benefits it provides. The state of a natural capital asset can be measured by its quantity (how much there is), quality (what condition it is in) and its location (where it is). Understanding the quality, quantity and location of natural capital assets will help to ensure that the provision of benefits and value to society can be sustained.

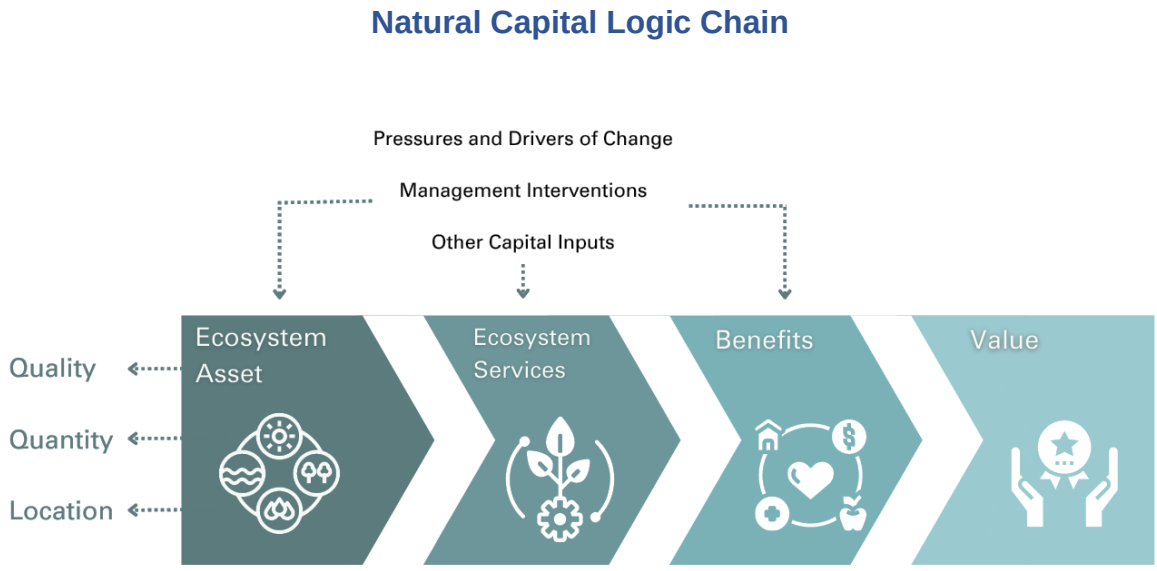

Figure 3 Natural England's natural capital logic chain (reproduced from Wigley et al., 2021)

Understanding the links between ecosystem services and natural capital assets enables us to understand which aspects of the natural environment are vital for the long-term provision of benefits. Natural England's Natural Capital Indicators project (Lusardi et al., 2018) identified the ecological and environmental properties that underpin the value of a natural capital asset. Natural England then built upon this work by mapping these natural capital indicators in their National Natural Capital Atlas and County and City Region Natural Capital Atlases (Lear et al., 2021).

The natural capital approach is described by Hooper et al. (2019) as *"a somewhat broad term that encompasses assessment of the quantity, quality, function and value of environmental assets and the goods and services that flow from them, with the aim of ensuring the sustainable use of natural resources. Fundamentally, the approach is based on recognising the contribution of nature to human welfare, and hence improving the manner in which the natural environment is traded-off against other things that are important to society. The concept of value is central to the natural capital approach, as it seeks to better integrate environmental and economic information and thus to redress the historic trend in which natural capital and ecosystem services were undervalued and overexploited. Equally important is documenting ecological status as the characteristics of assets are usually only partially reflected in monetary values."*

This project aims to provide a baseline assessment of the location, quality and quantity of natural capital assets on the Cumbrian Solway, using Natural England's logic chain as a template and drawing on their Natural Capital Indicators project and Cumbria's Natural Capital Atlas.

1.2.2 Implementing a natural capital approach

The Natural Capital Committee[2], suggest following these five steps to create a natural capital plan:

1. Set out a vision
2. Understand where you are starting from
3. Build the evidence base
4. Identify and assess the options
5. Implement and evaluate

The initial scoping stage of a natural capital project involves establishing a vision and a baseline for future planning and management. This can then be used to inform the development of an evidence base, which will include an inventory of all natural capital assets in the project area and their condition. It also includes a risk register, highlighting drivers of change and pressures that may change the natural assets, and impact on their provision of benefits. Finally, it should include natural capital accounts, where the assets are valued in monetary terms.

This project is an initial scoping project to, aiming to start the process of the natural capital approach. The next steps beyond this project should focus on a full asset inventory, condition assessment, risk register and natural capital accounting.

[2] The Natural Capital Committee (NCC) was an independent advisory committee which ran from 2012-2020. The NCC advised the government on natural capital.

1.2.3 Policy context

Several projects in Cumbria have identified priority outcomes relating to nature's recovery. Here, the opportunities identified in the Cumbria Local Nature Recovery Strategy, the Shoreline Management Plan refresh, the Cumbria Coastal Strategy and the Solway Coast AONB 2020-2025 Management Plan are reviewed for their opportunities to feed into the natural capital approach.

1.2.3.1 Cumbria Pilot Local Nature Recovery Strategy

In August 2020, the UK Government announced that Cumbria would be one of five areas to trial the development of a Local Nature Recovery Strategy (LNRS). The aim of the LNRS is to: *"restore and link up habitats so that species can thrive, and agree the best places to help nature recover, plant trees and woodland, restore peatland, mitigate flood and fire risk, and create green spaces for local people to enjoy. With an agreed LNRS in place, the nature recovery work of everyone in Cumbria - from the designated landscapes and large conservation partnerships, to farmers, local businesses and community groups - can help to deliver a bigger, better and more joined up nature recovery network across the whole of the county."*

In May 2021, the draft LNRS was submitted to Defra, this included a Statement of Biodiversity Priorities and a Local Habitat Map.

Cumbria Local Nature Partnership is building on this work by attempting to integrate spatial planning priorities around wetlands, water and coasts to help guide future work on the LNRS. The LNRS included terrestrial and coastal habitats but did not assess marine habitats.

The main outcomes of the LNRS for coastal habitats are as follows:

- Dynamic coastlines created supporting a diverse mosaic of habitats and providing a variety of food, shelter and nesting areas for common and rare species.
- Restore natural coastal processes to a healthy and functional state, to enable restoration of coastal and transitional habitats.
- Create natural coastal defence systems through restoration and appropriate management of coastal habitats and processes.
- Restore coastal habitats for the benefits this brings through 'blue carbon storage' (carbon sequestration).
- Improve water quality, by encouraging habitat restoration and reducing human impact.
- Promote and restore communities of native and characteristic coastal species.

Measures for delivery of the outcomes include:

- Restoring natural coastal processes including managed realignment.
- Restoring habitats including, kelp forests, seagrass beds, sand dunes, saltmarsh, shellfish beds including mussels and cockles.
- Reducing disturbance and damage to sensitive intertidal habitats, sea cliff bird colonies and sites for breeding birds.
- Improving water quality (through shellfish restoration).
- Tackling pollution and plastics.

Cumbria's LNRS produced The Cumbria Habitat Networks using Natural England's England Habitat Network model. The model uses the Cumbria Habitat Basemap and identifies areas,

zones or networks where targeted action for nature should occur. As the best available data was used in the model, the outputs should be used as a guide for where to focus further work to look for opportunities to restore and create habitats. The maps show existing important habitat areas, these are habitats that need to be conserved, enhanced or restored.

1. Primary Habitats – habitats identified on the Cumbria Habitat Basemap
2. Associated Habitats – other habitats also used by wildlife using the Primary Habitat
3. Habitat Restoration/Creation Areas – areas identified as currently being restored/created
4. Restorable Habitats – existing habitats which could be restored to a more wildlife-rich state

The maps also show habitat network areas:

1. Fragmentation Action Zone – where habitat restoration and creation will be of greatest help in connecting existing fragmented habitats to develop a habitat network (note this zone is within Network Enhancement Zone 1)
2. Network Enhancement Zone 1 – where actions (habitat restoration and creation) to help join up habitat and create a network should be targeted
3. Network Enhancement Zone 2 – land which may be less suitable for habitat creation but where other actions to increase biodiversity will help to join up other habitats
4. Network Expansion Zone – Wider zones where habitat restoration and creation will support the habitat networks

Combined maps for coastal habitats showing areas of habitat creation or restored habitat can be viewed and downloaded in pdf format from the Cumbria Biodiversity Data Centre.

The LNRS project also involved assessing the opportunities for recovering or enhancing biodiversity in each sub-region based on the Natural Character Areas (NCAs) for Cumbria defined by Natural England. For each NCA, key drivers of change were considered along with considerations of wider environmental benefits that could be achieved through habitat creation or restoration in that sub-region. Broad objectives for nature recovery within each sub-region were also identified. For the Solway Basin and the West Cumbria Coastal Plain, relevant coastal nature recovery objectives included:

- Conserve and enhance the internationally important coastal and estuary systems including intertidal flats, salt marshes, sand dunes, intertidal habitats, vegetated shingle and coastal cliffs inside and outside of designated areas.
- Restoration of coastal transition habitats and saltmarsh via managed retreat.
- Re-establish transitional habitats such as saline and brackish lagoons.
- Allow natural coastal processes to occur, including recovery of coastal transition habitats and saltmarsh via managed retreat
- Restoration of seagrass beds and native oyster beds
- Conserve, restore and connect coastal and estuarine habitats, particularly lowland raised bogs and stone-faced banks

(Cumbria County Council, 2020)

1.2.3.2 Shoreline Management Plans

The Shoreline Management Plan (SMP) provides a large-scale assessment of the risks associated with coastal processes. A plan covering the North West coast was adopted in 2010, setting out policies for the short, medium and long term. The SMP divided the Cumbrian Coast into 25 ‘policy areas’ with each area then split into ‘policy units’. In 2019, a SMP Refresh process commenced through a series review and development activities, such as subject-specific working groups, to make sure the SMPs are up to date, reliable and

visible. The SMP Refresh has been designed to ensure SMPs can be easily maintained and remain 'living' documents.

The SMP policies describe how each stretch of coastline is most likely to be managed to address flood and erosion risks. These policies are: No active intervention, hold the line, managed realignment, and advance the line. Managed realignment allows the shoreline to move backwards or forwards, this could involve introducing new measures to reduce erosion or create new defences landward of the original defences. This strategy provides potential for habitat creation where areas that were previously behind sea defences or embankments can now become intertidal habitat. More detail on potential habitat creation sites identified by the SMP can be found in Section 6.1.5.

1.2.3.3 Cumbria Coastal Strategy

The Cumbria Coastal Strategy is a plan for managing coastal flood and erosion risks. This builds on the policies set in the North West SMP, setting out the best approaches to carry out those policies. The work is being carried out by Cumbria County Council who is working with the Cumbria Coast Protection Authorities and the Environment Agency to develop a strategy for the future management of the coast from Arnside to the Scottish Border.

1.2.3.4 Solway Coast AONB 5-year Management Plan

The Solway Coast Area of Natural Beauty (AONB) is designated for its special character as a place that needs conserving and enhancing, while considering the needs of the local community.

The AONB has a five-year statutory management plan which guides the work of organisations and communities in the area. The AONB's 2020-2025 Management Plan lays out priority actions for nature recovery for the area's seascapes and intertidal landscapes including the Inner Firth's intertidal flats and saltmarsh and the outer Firth's beaches and dunes. These include:

- promoting rewetting of degraded saltmarshes;
- restoring reclaimed farmland to marshland;
- managing wildlife disturbances;
- encouraging the natural erosion and development of saltmarsh;
- enhancing natural saltmarsh features through drainage blocking and adding pools and wet features;
- reducing pollution from agricultural run-off;
- restoring natural dynamic dune systems that have been lost to coastal squeeze or overstabilisation;
- creating more wet features within the dune system and
- controlling invasive species.

For a comprehensive list of actions refer to the AONB's 2020-2025 Management Plan.

2 Approach

This project has two elements to the Marine Natural Capital Development assessment:

1. Research
2. Consultation

An initial desk-based review of the Solway's natural capital was undertaken early on in the project. Results of this are presented in Section 3. A workshop was then held with stakeholders, outcomes of the workshop are outlined in Section 4. The workshop helped to focus the following research which is reported in Section 5 onwards. Throughout the project, one-to-one conversations were held with stakeholders and other organisations carrying out relevant natural capital habitat restoration work around the UK.

3 Baseline assessment of the Solway's Natural Capital assets

3.1 Regional context

The Solway Firth is the UK's third largest estuary. It is a highly dynamic system with a vast tidal range that experiences great surges of sediment, with mobile banks and channels. The Solway Firth covers two National Character Areas (NCAs), the Solway Basin, which covers the area from the inner Solway down to Maryport, and the West Cumbria Coastal Plain, covering the area from the outer Solway to St. Bees Head.

The inner Solway is characterised by extensive areas of highly mobile sandflats and mudflats, etched by shifting and branching channels. The intertidal expanse is bordered by grazed saltmarsh. These habitats support internationally important populations of wildfowl and waders. Further south, the coastline is more exposed and is made up of coarser sediments, intertidal sandflats, and occasional boulder scars, bordered by narrow sand and pebble beaches, backed by low cliffs or sand dunes. The vegetated shingle and dune communities in this area are internationally important and designated as an Area of Outstanding National Beauty (AONB). The narrow strips of sand dunes support populations of the rare natterjack toad. The southern area of the outer Solway between Maryport and St. Bees Head is characterised by a mixture of intertidal flats, beaches and coastal defence works. Coastal erosion is prominent in this area and eroded material is moved northwards, feeding the beaches of the Solway AONB. Moving towards St Bees Head, the coastline is dominated by intertidal sands and mudflats, saltmarsh and sand dunes before reaching the red sandstone cliffs and shingle beaches of the headland itself (Natural England, 2014).

As well as the information provided in the NCA profiles, the Solway Review (Solway Firth Partnership, 2022) provides an in-depth baseline assessment covering the environmental, physical and economic aspects of the Solway Firth.

3.2 Drivers and pressures

Compared to other estuaries in the UK the Solway Firth is relatively undeveloped and is not densely populated, or heavily industrialised (Figure 4).

For a comprehensive list of the drivers of change for the Solway Basin and West Cumbria Coastal Plain see the LNRS Appendix 2 - NCA templates (Cumbria County Council, 2020).

These cover: Nature Recovery Agenda, Agriculture and Environment Policy, Agricultural Profitability, Climate Change, Planning and Development Pressures, Government Policy, Health and Wellbeing, Tourism and Outdoor Recreation, Flood Management, Energy Production and Water Environment, Agricultural Change and Land Management, Water Quality, Local Development Planning, Economic Development, Public attitudes, Finances, Coastal realignment, Transport Infrastructure, Planning and Strategy.

Pressures to the Marine and Coastal Environment in the Irish Sea

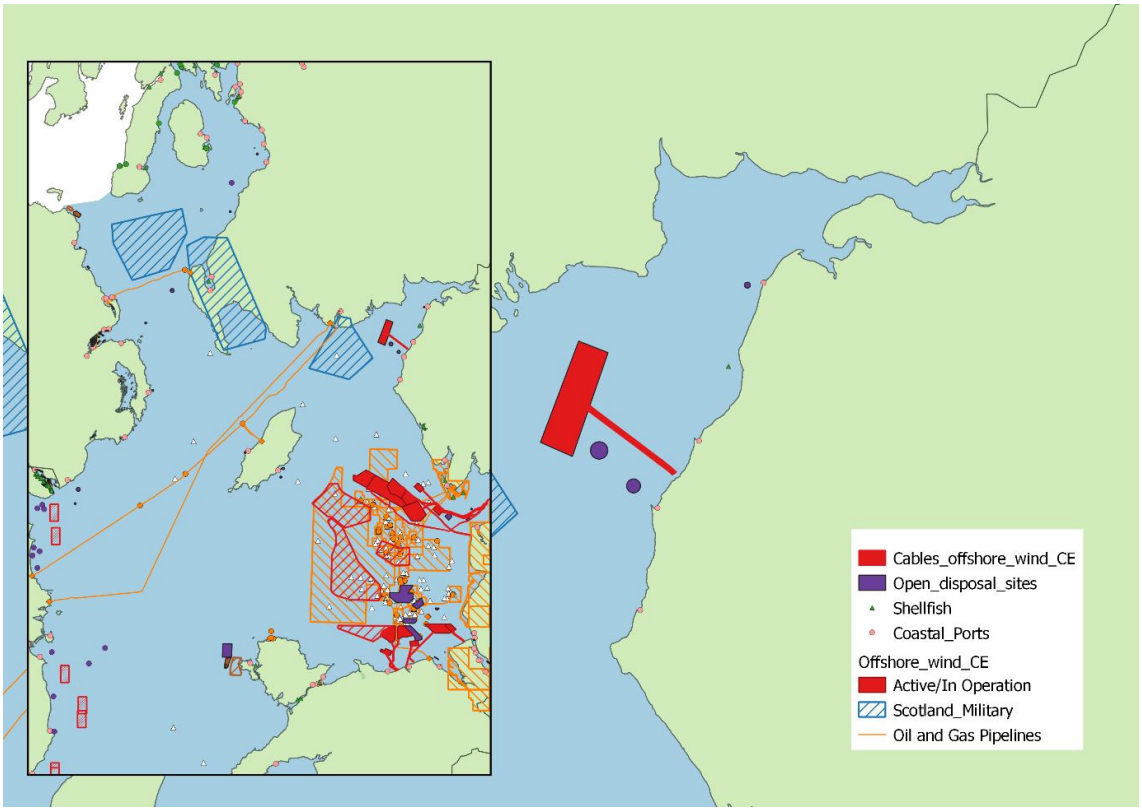

Figure 4 Relatively low levels of activity on the English Solway Firth compared to the rest of the Irish Sea (left). Cumbria Wildlife Trust.

3.2.1 Climate change

Climate change will present one of the great challenges to coastal communities through a number of ways including, rising sea levels, increased frequency of storm events, and extreme temperatures. These pressures will lead to increased coastal erosion, higher flood risk and coastal squeeze. Both flooding and coastal erosion have been identified by the Cumbria Coastal Strategy (Cumbria County Council, 2020) as key issues along the inner and outer Solway respectively. Climate Central's Sea Level Rise and Coastal Flood Risk Maps show large areas of the inner Solway will be below annual flood level by 2100.

3.2.2 Economic drivers of change

It is important to understand the economic setting of the area because certain economically important activities can also drive change. The Socio-Economic Analysis of the English Solway (SEAES) project report reviews the socio-economic uses of the English side of the Solway Firth (EKOS Limited and Solway Firth Partnership, 2020). It includes an assessment of: sea fisheries; seafood processing; shipping and transport; energy; aggregates subsea cables and pipelines; sport recreation and tourism; historic environment and cultural heritage; and marine management and education.

Table 1 shows an economic overview of the marine sector in the English Solway Firth, with changes over the previous five years. The core marine sectors in the area are sea fishing, mainly for shellfish, and shipping and transport, with the two freight ports located at Silloth and Workington. The ancillary marine activities include fish processing, defence, energy, and recreation and tourism, with yachting marinas located in Whitehaven and Mayport. Sea fisheries and sport recreation and tourism are the key economic contributors.

Table 1 Economic Contribution of the English Solway Firth 2014-2918 Adapted from SEAES report (EKOS Limited and Solway Firth Partnership, 2020)

	Employment		**Turnover**		**GVA**	
	Total	% Change	Total	% Change	Total	% Change
Core Marine Sector Activity						
Sea Fisheries	35	+133%	£3.4m	-34%	£1.5m	-33%
Shipping and Transport	40	-47%	n/a	n/a	n/a	n/a
Total economic contribution	**75**	**-17%**	**£3.4m**	**-34%**	**£1.5m**	**-33%**
Ancillary Marine Activity						
Fish Processing	100	-33%	n/a	n/a	n/a	n/a
Defence	175	-22%	n/a	n/a	n/a	n/a
Energy	80	+14%	n/a	n/a	n/a	n/a
Sport, Recreation and Tourism	4,245	+2%	£148m	-23%	£53m	-5%
Total economic contribution	**4,600**	**0%**	**£148m**	**-23%**	**£53m**	**-5%**

Recommendation

Map the socio-economic uses of the Solway

3.2.3 Water quality

Both the Solway and Solway Outer South water bodies achieved 'Good' status for dissolved inorganic nitrogen content and 'high' status for all specific pollutants. However, the chemical status of both water bodies is classified as 'fail' due to mercury and Polybrominated diphenyl ethers (PBDE) levels. The Solway water body has 'poor' ecological status because of phytoplankton levels, which has been attributed to poor nutrient management by the livestock agriculture and land management sector. The Solway Outer South water body has 'moderate' ecological status due to invertebrate levels, also due to poor soil management by the agricultural sector.

3.3 Asset inventory

The asset inventory gives an overview of the types of marine and coastal natural capital assets in the area. This section reviews the location and quantity of priority coastal habitats, broadscale marine habitats, fisheries, birds, marine mammals, protected areas recreational uses. This is not a complete inventory and should be viewed as the starting blocks on which a full assessment can be built.

3.3.1 Priority coastal habitats

Priority habitats are those that were identified as being the most threatened and requiring conservation action under the UK Biodiversity Action Plan (UK BAP). They are now referred to as 'habitats of principal importance under Section 41 of the 2006 Natural Environment and Rural Communities (NERC) Act'. Figure 5 shows the distribution of marine and coastal Priority Habitats on the English side of the Solway and Table 2 shows the area covered by each. The coast is dominated by coastal saltmarsh (after areas of 'no main habitat but additional habitats present'), highlighting their regional importance.

Table 2 Extent of coastal Priority Habitats in the English Solway Firth

Priority Habitat	Area (ha)	% of national resource	% of Cumbria's resource in Solway Basin NCA
Coastal saltmarsh	2838.20	8.73	64
Coastal sand dunes	242.20	2.24	15.1
Coastal vegetated shingle	11.53	0.28	38.3
Maritime cliff and slope	157.53	1.38	5.8
Mudflats (intertidal)	126.75	0.16	8.4
No main habitat but additional habitats present*	6067.87		
Saline lagoons	16.06	1.15	1.5

**an area is classified as 'no main habitat but additional habitats present' where the habitats present are either of lower confidence or cannot be accurately mapped*

Priority Coastal Habitats

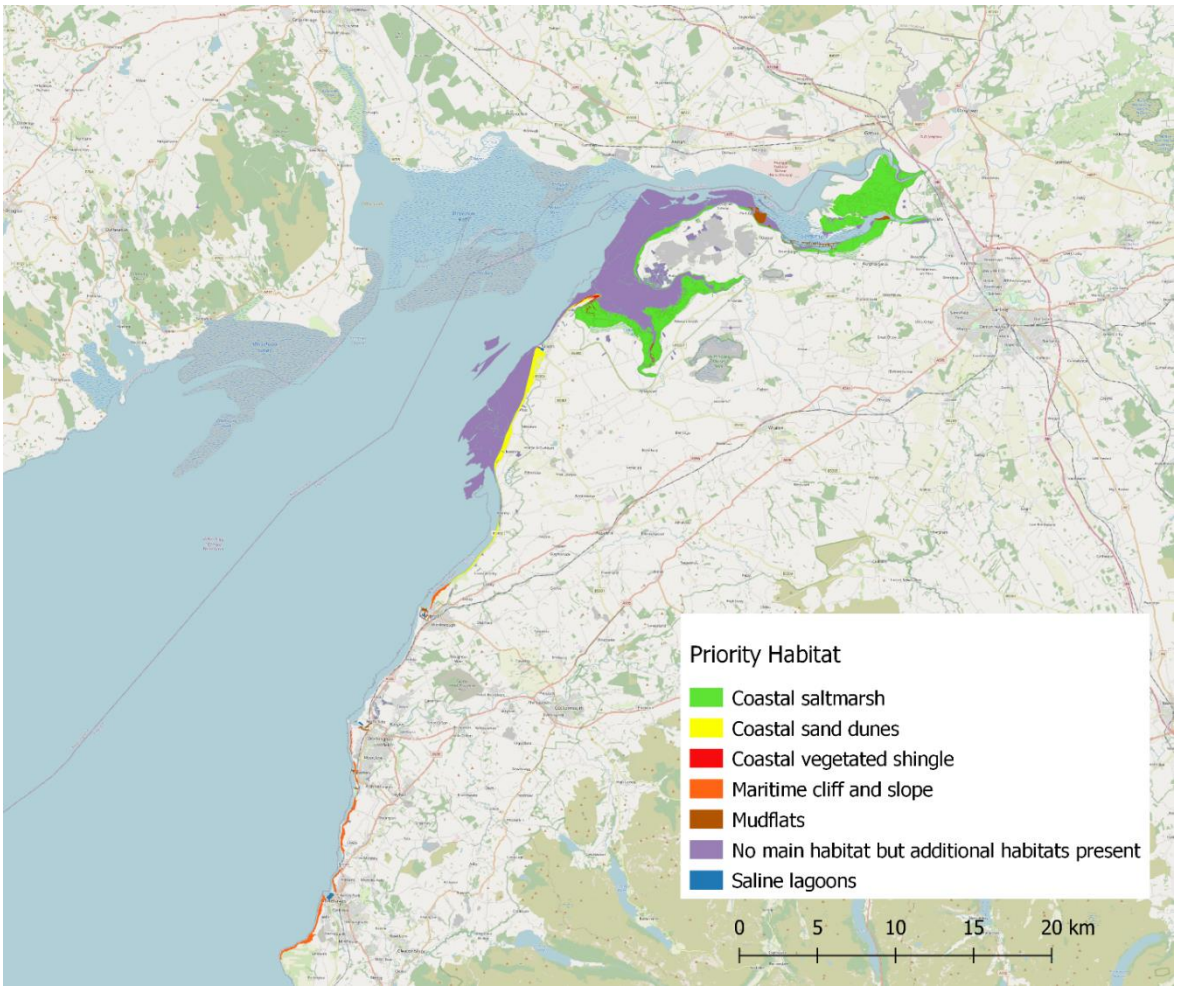

Figure 5 Priority Habitats in the Solway Firth. Data sourced from Natural England's Priority Habitats Inventory, 2021. © OpenStreetMap contributors. Data is available under the Open Database License

3.3.2 Broadscale marine habitats

Figure 6 shows the distribution of EUNIS[3] broad scale marine habitats in the Solway and Table 3 shows the area covered by each. Circalittoral sandy mud is the most predominant marine habitat in the Solway, making it the habitat with the greatest potential to provide high value ecosystem services, particularly carbon storage (Gregg et al., 2021) and habitat provision (Fletcher et al., 2012).

[3] European Nature Information System- a comprehensive pan-European system for habitat identification

Table 3 Extent of EUNIS broadscale marine habitats in the English Solway Firth

EUNIS Broadscale Marine Habitats	Area (ha)
A3.1: Atlantic and Mediterranean high energy infralittoral rock	659
A4.1: Atlantic and Mediterranean high energy circalittoral rock	12,136
A5.13: Infralittoral coarse sediment	243,827
A5.14: Circalittoral coarse sediment	1,395,937
A5.15: Deep circalittoral coarse sediment	1,824,260
A5.23 or A5.24: Infralittoral fine sand or Infralittoral muddy sand	7,477,838
A5.25 or A5.26: Circalittoral fine sand or Circalittoral muddy sand	8,417,157
A5.27: Deep circalittoral sand	**12,840,449**
A5.33: Infralittoral sandy mud	438,369
A5.35: Circalittoral sandy mud	**24,015,734**
A5.37: Deep circalittoral mud	71,690
A5.43: Infralittoral mixed sediments	3,859
A5.612: ***Sabellaria alveolata*** on variable salinity sublittoral mixed sediment	9,390
A5.62: Sublittoral mussel beds on sediment	278,775
A5.625: [***Mytilus edulis***] beds on sublittoral sediment	2,070

EUNIS Broadscale Marine Habitats

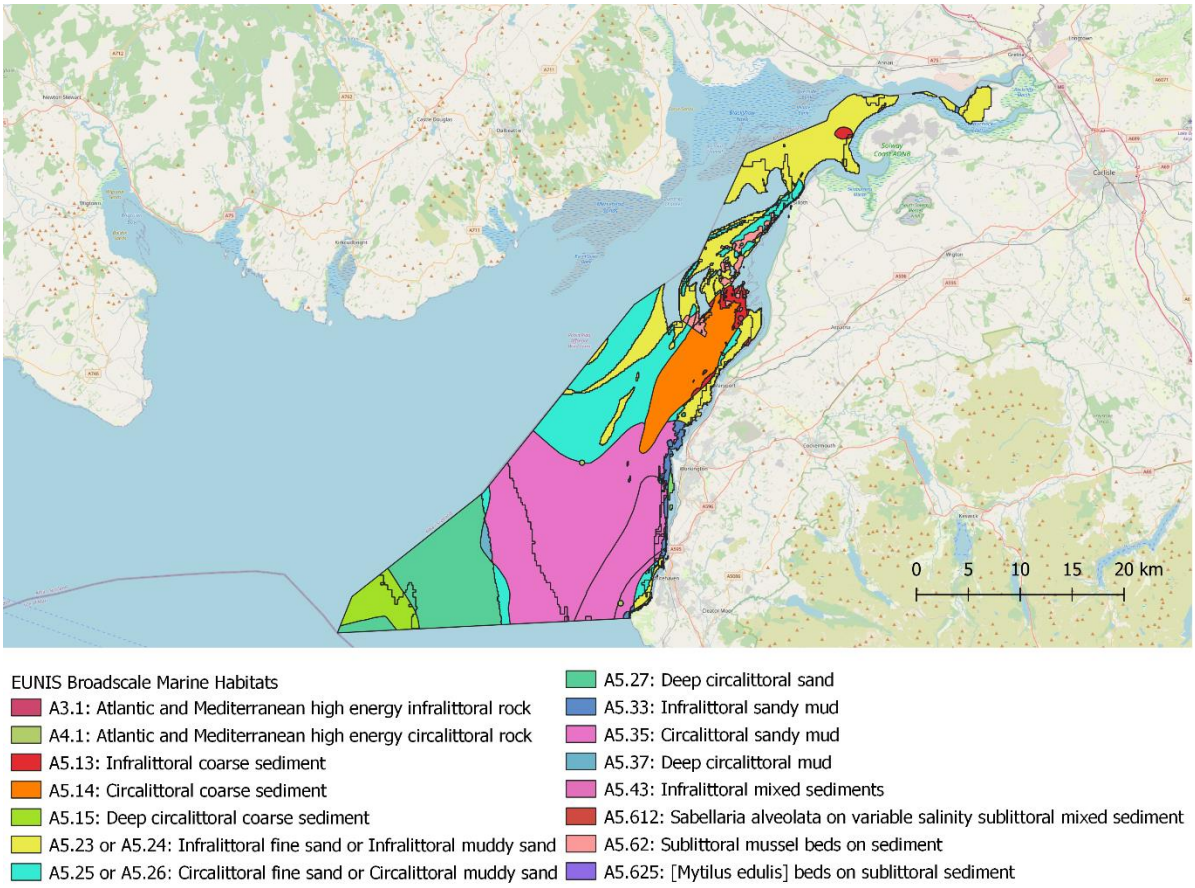

Figure 6 . EUNIS broadscale marine habitats in the English Solway Firth. © OpenStreetMap contributors. Data is available under the Open Database License

3.3.3 Priority species

Priority species in Cumbria have been identified as part of the LNRS, this list does not cover marine species due to the limitations of the scope previously mentioned, however, it does include coastal species and anadromous fish.

The NCAs also list priority species in each sub-region. However, the list for the Solway Basin and West Cumbria Coastal Plain are still under review as part of the LNRS work (Cumbria County Council, 2020). A provisional list, identified by the Solway Coast AONB Management Plan 2020-2025 is given below:

- Breeding and overwintering wildfowl and waders
- Little tern
- Marsh fritillary
- Natterjack toad
- Mud shrimp
- Wrasse
- Smallhound

- Bass
- Bell huss
- Thornback ray
- Atlantic salmon
- Tope dogfish

3.3.4 Protected areas

Since the boundaries of the Special Protection Area (SPA) were extended in 2020, Marine Protected Areas cover almost 100% of the English Solway Firth (Figure 7). Table 4 shows the extent of the many statutory and non-statutory designations in the English Solway Firth.

Table 4 The extent of marine and coastal statutory and non-statutory designations covering the English Solway Firth area.

Type	Name	Year of Designation	Total area covered (km^2)
Marine Conservation Zone (MCZ)	Allonby Bay	2016	39.00
	Cumbria Coast	2013	22.00
	Solway Firth	2019	44.15
Site of Special Scientific Interest (SSSI)	Upper Solway Flats and Marshes	2011	129.50 (English only) 378.42 (Scottish and English)
	Silloth Dunes and Mawbray Banks	1991	1.90
	River Eden and Tributaries	1997	24.49
	Maryport Harbour	1989	0.04
	St Bees Head	1995	1.57
Special Area of Conservation (SAC)	Solway Firth	2005	436.76
Special Protection Area (SPA)	Solway Firth	2020	1357.49
Area of Outstanding Natural Beauty (AONB)	Solway Coast	1964	115.00
Non-statutory designation	RSPB- Campfield Marsh	1987 (purchased site)	3.35

Designated Sites

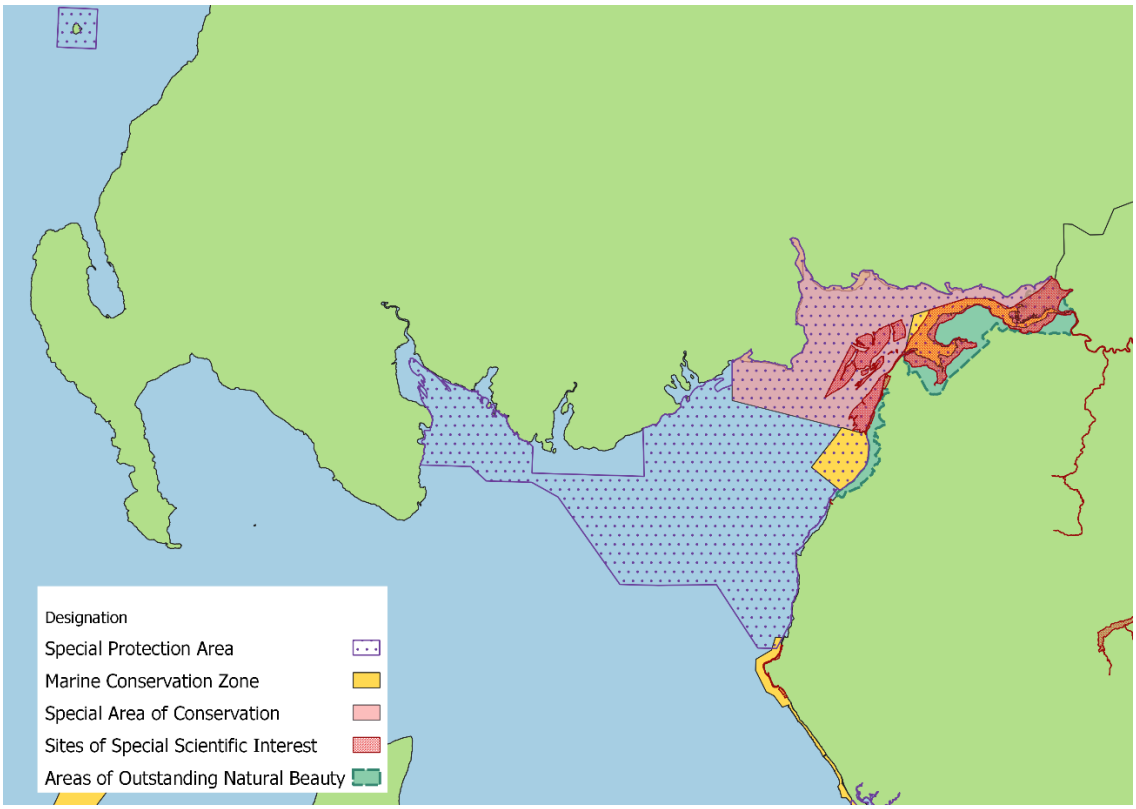

Figure 7 Statutory and non-statutory marine and coastal designated sites of the English Solway Firth.

3.3.5 Conditions of designated areas

Natural England assesses the condition of its designated areas on a six-yearly cycle. Because many of the Solway's protected areas were recently designated, after the last condition assessments were carried out, there are no condition assessments for many of the sites. The condition of the Solway coast's SSSIs are presented in Table 5. In most areas covered by SSSIs, designated features have been classified as in 'unfavourable-recovering' condition.

Table 5 Condition of the Solway Coast SSSIs

	Condition			
	Favourable	**Unfavourable-Recovering**	**Unfavourable-No Change**	**Unfavourable-Declining**
% area of SSSI	29.4	66.7	3.8	0.1

3.3.6 Fisheries

3.3.6.1 Fish and shellfish stocks

Historically, in the Solway Firth, commercial fishing was relatively diverse with Dover sole and herring being key components of the catches. Over the last few decades, the main landings have been shellfish from both within and outside of the Solway Firth, particularly king and queen scallops, but also whelks, razor clams, lobsters and brown shrimp. Whitehaven is the main landing port, accounting for 70% of landings by value. Since 2013, there has been a reduction in landings and a decrease in value of the catch, driven by a fall in king and queen scallop, as well as *Nephrops* (scampi or langoustine) catches, and an increase in the price of shellfish.

Cockle fisheries: In the middle of the Solway there was historically a large cockle bed called Middle Bank, as well as intertidal beds near Cardurnock and Beckfoot. All of the Solway cockle fisheries are now closed under byelaws as their cockle populations (which are also an important bird food resource) are too low to support a fishery. Data is lacking for current populations, however, the North Western Inshore Fisheries and Conservation Authority (NWIFCA) are looking to fill this data gap over the next year.

Mussel fisheries: Historically there have been both a vessel-based dredge fishery and a hand-gathered intertidal fishery for mussels on the Cumbrian Solway. Typically, the hand-gathered fishery has been small and there has been limited activity over recent years due to lower mussel populations. Until recent years there has been a larger subtidal mussel dredge fishery in the Silloth Channel, this fishery was not large or regular but it was important for local boats who take advantage of multiple fisheries. Since Defra's revised approach to fishing in Marine Protected Areas (MPA) and the introduction of the NWIFCA's *Restrictions on the use of a dredge* byelaw, any mussel fishery would now have to undergo a robust Habitats Regulation Assessment (HRA).

Brown shrimp: There is a shrimp fishery in the inner Solway, in the channels of Maryport and Silloth ports. This is takes place seasonally using beam trawls. This activity has undergone a Habitats Regulations Assessment (HRA) as it occurs within the Solway Firth SPA and SAC.

There is also some small-scale netting for sea fish that occurs.

The Solway is also known to be used as migratory passage for sea lamprey and river lamprey, these are features of the Solway Firth SAC. Atlantic salmon also use the estuary to migrate into rivers to spawn, and are a feature of the River Eden SAC. Haaf netting, an artisanal fishing technique for catching salmon, has been practised on both the Sottish and English side of the Solway Firth for hundreds of years. It is still used on the estuary today; however, critically low Atlantic salmon populations mean that there are now restrictions on the numbers of haaf netting licences that the Environment Agency issues on the English side of the Solway, in addition, there is a catch and release policy on the Scottish side of the Solway.

Several commercially important species use the Solway for spawning grounds including: sprat (*Spratus Spratus*), nephrops (*Nephrops norvegivus*), whiting (*Merlangius merlangus*), herring (*Culpea harengus*), cod (*Gadus morhua*), plaice (*Pleuronectes platessa*) and sole (*Solea solea*) (Coul et al., 1998). Allonby Bay is also thought to be a spawning ground for thornback ray, which is also one of the most commonly landed species in the area.

3.3.6.2 Value of fisheries in the Solway

The ICES rectangle 38E6 covers the entire Solway Firth but gives the best estimate of the value of fisheries in the project area. Table 6 shows the value of landings by the UK fleet in 2020. It shows the importance of shellfish in comparison to pelagic and demersal fish species (Marine Management Organisation, 2021).

Table 6 Landings of Fish Species Groups by the UK Fleet in 2020 by ICES Rectangle 38E6 (Marine Management Organisation, 2021)

	Pelagic landings	Demersal landings	Shellfish landings
Live weight (tonnes)	0	12	82
Value (£ million)	0.00	0.01	0.19
Value per tonne (£)	5,454.55	981.97	2,349.09

3.3.7 Seabirds and water birds

The Solway Firth is an internationally important area for seabirds and water birds, and is particularly important for its use by over wintering migratory populations particularly of red throated diver (*Gavia stellata*), great crested grebe (*Podiceps cristatus*), Slavonian grebe (*Aythya marila*) and the red-breasted merganser (*Mergus serrator*). It is recognised as the UK's sixth most important site for water birds, with populations of wildfowl and waders reaching over 140,000 (AONB, 2020). The inner Solway is home to pink footed geese, whooper swans and a variety of dabbling duck species from pintail to wigeon. The site supports the entire overwintering population of Svalbard Barnacle geese, with numbers over 40,000. It is also important for wading birds such as oystercatcher, curlew and dunlin. Breeding birds such as lapwing and redshank are also present. The Solway Firth SPA, recognises the importance of this site with 29 species of birds identified as designation features. St Bees Head SSSI is an 8km stretch of coast encompassing areas of shingle beach, cliff and cliff-top grassland. The cliffs provide the only breeding sites on the Cumbrian coast for colonial seabirds including: Black guillemot (*Cepphus grille*), Fulmar (*Fulmaris glacialis*), Guillemot (*Uria aalge*), Kittiwake (*Rissa tridactyla*), Puffin (*Fratercula artica*), Razorbill (*Alca torda*) and Shag (*Phalacrocorax aristotelis).*

For a full summary of the importance of birds and their protections in the Solway see the Solway Review chapter on birds.

3.3.8 Marine mammals

The waters around the North West of England are less important for marine mammals than other regions, due to the relatively shallow, uniform depth water. Although sightings are infrequent, bottlenose dolphin (*Tursiops truncates)* and common dolphin (*Delphinus delphis)* are both present in the Solway Firth. Harbour porpoise are the most commonly spotted cetacean in the Solway and are typically seen around St Bees Head, and Silloth (SeaWatch Foundation, 2022). Allonby Bay has been identified as a potential pupping ground for harbour porpoise (*Phocoena phocoena*). Risso's dolphins (*Grampus griseus*), white beaked dolphins (*Lagenorhynchus albirostris*) and minke whale (*Balaenoptera acutorostrata*) are also present in the Solway but are rarely encountered and prefer to stay offshore in deeper waters.

Common Seal (*Phoca vitulina*) and Grey Seal (*Halichoerus grypus*) are both present in the Solway Firth but do not make significant contributions to the UK population. Sightings of Grey Seals have been recorded near St. Bees and Parton Bay by Sea Watch.

3.3.9 Recreational uses

The Solway Coast offers many popular beaches and walking routes for locals and visitors, it is popular for its tranquillity and wild, wide-open spaces. Walking routes include the Hadrian's Wall Path and the England Coast Path, which is open between Allonby and Whitehaven and approved but in progress between Allonby and Gretna on the Scottish border. The coastline also has a rich maritime history with several sites of historical importance, visitor centres and museums on the coast. For example, Hadrian's Wall Heritage Site and World War Two airfields.

Despite its beauty, the Solway Coast is often overshadowed by the Lake District National Park and does not attract as many tourists and visitors to the area. The 'People and Place section of the 5-year AONB Management Plan 2020-2025, suggests actions for improving the areas attractiveness such as increasing opportunities for heritage related walking and cycling and improving the accessibility and condition of pathways this should enhance the cultural services derived from the area.

4 Stakeholder engagement

A key aspect of the project was consultation with both stakeholders with an interest in marine natural capital on the Solway, and organisations carrying out relevant projects elsewhere.

4.1 Stakeholder/ relevant project communication

A list of potential contacts was collated as a first step in the project. The list was based on contacts on the Solway Firth Partnership Advisory Group, as well as people already involved in the Scottish Solway marine natural capital project. Other contacts were included from local universities, as well as people and organisations linked to the projects and networks of Cumbria Wildlife Trust.

A list of other relevant marine natural capital projects or marine and coastal habitat restoration projects was also created and contact was made with relevant people on those projects to set up meetings.

Table 7 shows a list of the organisations that were consulted throughout the project.

Table 7 Organisations that were consulted during the project and the type of communication.

Organisation /Project	Type of contact
Arran Coast	1 to 1 meeting
Associated British Ports	Workshop
Galloway and Southern Ayrshire Biosphere	1 to 1 meeting
BLUE Marine Foundation	1 to 1 meeting
Crichton Carbon Centre	1 to 1 meeting
Cumbria County Council	Workshop
Cumbria Local Nature Partnership	1 to 1 meeting
Cumbria University	Email
Cumbria Wildlife Trust	Workshop and 1 to 1 meeting
DEEP and Herriot Watt University	1 to 1 meeting
Dynamic Dunescapes	1 to 1 meeting
Eden Catchment Partnership	Meeting
Environment Agency	Workshop and 1:1 meeting
Essex Wildlife Trust	Email
Lancaster University	Email
Loch Ryan Oyster Fishery	1 to 1 meeting
Marine Management Organisation	Workshop and email
National Trust	Email
Natural England	Workshop, 1 to 1 meetings and email
Nature Scot	1 to 1 meeting
North West Coastal Forum	Workshop
North West Inshore Fisheries Conservation Authorities	Workshop and 1 to 1 meeting
Project Seagrass	1 to 1 meeting
ReMeMaRe	Email
RSPB	Workshop, 1 to 1 meeting and email
Seawilding	1 to 1 meeting
Solway Firth Partnership Advisory Group Members	Workshop and email
Solway Coast AONB	Workshop and email
The Crown Estate	Workshop and 1 to 1 meeting
The Scottish Wildlife Trust	1 to 1 meeting
The Wildlife Trust, Central Marine Team	Workshop, 1 to 1 meeting and email
University of Central Lancashire	Email
University of Glasgow	1 to 1 meeting
West Cumbria Rivers Trust	Workshop
Wildfowl and Wetlands Trust	1 to 1 meeting
Yorkshire Marine Nature Partnership- Wolds Environmental Consulting Ltd and Hull University	1 to 1 meeting
Yorkshire Wildlife Trust	1 to 1 meeting

4.2 Stakeholder workshop

An online workshop was held through *Zoom* in early February 2022. Prior to the workshop a list of questions was circulated to all participants for prior consideration, and for those who could not attend to have the ability to respond via email. The purpose of the workshop was to establish stakeholders' thoughts, opinions and priorities for potential marine natural capital work on the Solway. An introductory presentation was given, summarising the work so far, (background to the project, a brief overview of the natural capital approach, the key habitats in the project area and the ecosystem services they provide). The participants were then asked to answer the following questions and a *Miro* board (an online whiteboard) was used to capture key points from the discussions:

1. What is already happening on the Cumbrian Solway? Are you aware of any projects on marine habitat restoration/enhancement, natural capital or community-led initiatives?

2. What is going well for the Solway's marine natural capital habitats and what is not going so well?

3. What are the most important benefits provided by the Solway's coastal/marine natural capital habitats and who benefits?

4. What are the most suitable priorities on the Cumbrian Solway for:
    a) restoration,
    b) reintroduction,
    c) expansion,
    d) enhancement,
    e) and protection,

and if funding became available for coastal marine natural capital work, what would be your top priority?

5. Have we missed any other marine/coastal habitats or species that should be considered? [other than saltmarsh, sand dunes, seagrass and biogenic reefs (native oysters, Sabellaria, blue mussels)]

6. Can you suggest any locations that may be suitable for future restoration/expansion work? (a map was provided for participants to select locations on)

7. Do you know where the best and most up to date data is for existing and historic habitats?
8. Do you have any advice for collaborative projects, or how future marine natural capital projects should be approached?

9. How can this project best feed into your current or future work?

10. In what ways could the local community get involved in future marine natural capital work?

11. What relevant work is happening elsewhere? Who would be best to approach for advice?

12. The Solway is largely understudied and could be a good study site. Does anyone have experience working with universities?

4.2.1 Key outcomes of the workshop

A number of successes and positive work already being undertaken on the Solway were highlighted. These included:

- The Dynamic Dunescapes project undertaking activity at Mawbray Banks and Grune Point. The engagement and citizen science aspects have been particularly successful.
- New conservation designations including:
    - Solway Firth Marine Conservation Zone (MCZ), designated in 2019 – to protect the Species of Conservation Importance, European smelt.
    - Allonby Bay MCZ, designated in 2016 – to protect 14 features including honeycomb worm reefs and blue mussel beds.
    - Cumbria Coast MCZ designated in 2013 – to protect 8 features including honeycomb worm reefs and razorbill, which were added as a designation feature in 2019.
- St Bees Head Voluntary Code of Practice established in 2018 – restricting the use of nets during the seabird breeding season.
- Saltmarsh enhancement work undertaken at Rockcliffe Marsh by Natural England, Castleton Estate and Cumbria Wildlife Trust, and at Campfield Marsh by the RSPB.
- Litter picks around the coast with active leadership from volunteers and community involvement.
- Facilitated groups, such as the Cumbria Farmer Network, providing support and shared learning with farmers.
- The Cumbria's SMP Refresh planning to focus on a habitat restoration for sand dunes and saltmarsh, with an emphasis on how they contribute to coastal defence as well as other natural capital benefits.
- Gathering of evidence of European smelt populations in the Solway Firth by the Environment Agency and Solway Firth Partnership.

The main issues and concerns for the Solway area included:

- Recreational bird disturbance
- Vandalism
- Water quality – high levels of mercury within Allonby Bay MCZ, sewage issues around Whitehaven,
- Bathing waters – Silloth has been de-designated as a bathing water due to concerns over strong currents
- Solway Shore citizen science reports are outdated
- Data - lack of data, highly scattered, and more needed. Natural England are carrying out MPA condition assessments, an outcome of this will be greater monitoring and more available data.
- Invasive species – several marine Invasive Non-Native Species (INNS) have been identified in the Solway Firth. These include: Japanese wireweed *(Sargassum muticum*), Pacific oyster (*Magallana gigas* previously *Crassostrea gigas*), **Common cord grass (*Spartina anglica*)**, Orange tipped sea squirt (*Corella eumyota*), **Acorn barnacle (*Elminius modestus*)**, Leathery sea squirt (*Styela clava*), Green sea fingers (*Codium fragile*), Japanese skeleton shrimp (*Caprella mutica*), **American Lobster (*Homarus americanus*) and Tube worm (*Ficopomatus enigmaticus*)**. Those highlighted in bold are currently present in the English Solway (Solway Firth Partnership, 2021).

The priorities for future work:

Discussion took place on the key benefits provided by the Solway's coastal and marine habitats. It was noted that they are all interlinked so choosing the most important benefits is difficult. However, biodiversity enhancement, improved water quality and climate change mitigation, were highlighted as key areas that underpin most other naturally-derived benefits.

It was noted that it is particularly difficult at this stage to decide on the beneficiaries. Beneficiaries could be split into local, regional, national and international, but categorising groups any further could be more difficult. To get a better, more detailed idea of who benefits from the Solway's marine natural capital assets, the assets would need to be mapped and the benefits linked and tracked to individual groups of people. Conducting this kind of activity could be difficult with the data available at present, however, it could be addressed in future work. There was however, a detailed discussion around how the benefits derived from the Solway's coastal and marine environment such as, health and wellbeing, tourism and recreation and food provision (fisheries and marsh grazing), are recognised by all communities, from local to international.

Recommendation

Better understand and map who the beneficiaries are

The following considerations were also discussed when deciding on priorities for future natural capital work:

- The need to refer to the Natural Capital Atlas for Cumbria, produced by Natural England to see most important assets in the area.
- More data is needed before deciding on priorities for restoration.
- The need to understand how assets will be impacted by the effects of climate change and other drivers of change. There will be no point putting effort into reintroducing or restoring something that is vulnerable to future change because it will not be successful or sustained in the long-term.
- It will be important to do further research into the accretion and erosion of saltmarshes, and understanding the dynamics of associated mudflats.

Stakeholders agreed that the priority areas for protection and restoration would be:

- Sand dunes
- Saltmarshes
- Water quality

Stakeholders discussed potential for the introduction of seagrass, however, historical data on the presence and extent of seagrass meadows in the Solway would be needed to justify introduction. Furthermore, an understanding of how such an introduction would impact upon current habitats in the area would need to be taken into account. No recommendations were made for expansion or enhancement priorities.

It was suggested that a full inventory of all of the Solway's coastal and marine natural capital habitats and species should be made. This goes beyond the scope and timescale of the current project, however, it would be recommended for future work.

> Recommendation
>
> Complete a full marine and coastal natural capital asset inventory for the Solway

When asked whether stakeholders knew of any suitable locations for restoration of natural capital could take place, the suggestions were to:

- Refer to locations in the Shoreline Management Plan
- Refer to Natural England's Natural Capital Atlas
- Gain greater knowledge and more data before deciding on locations
- Sites and restoration work should complement current projects in the region such as Dynamic Dunescapes and the RSPB's LIFE on the Edge project, there may be potential to carry out work on sites shortlisted but not chosen for these projects.

> Recommendation
>
> Carry out further monitoring and data collection on the marine and coastal assets

5 Focus and priorities

As suggested during the workshop, Natural England's Natural Capital Atlas' were considered. These show the natural capital assets of most significance to each region. From these, it is clear that saltmarshes are of particular importance in the Solway, as well as beaches (including intertidal sediment), shallow subtidal sediments and intertidal rock. This conclusion supports the outcomes from the discussions in the workshop and the consultation with stakeholders. Therefore, saltmarshes have been used as an example for producing a logic chain relevant to the Solway Firth. Although there was not scope to produce further logic chains during the current project, it may be worth considering producing them for the following priority species and habitats in any future natural capital work undertaken in the Solway:

1. Sand dunes
2. *Sabellaria* reefs
3. Blue mussels
4. European smelt

> Recommendation
>
> Produce logic chains for the Solway's key natural capital assets

The importance and restoration potential of seagrass meadows and native oysters were considered during the early stages of the project because of their numerous benefits and their importance on the Scottish side of the Solway Firth. Nevertheless, they were not considered further during this project.

Seagrass is an important natural capital asset and it is present in many locations on the Scottish side of the Solway. On the English side of the Solway however, there are no known locations where seagrass is currently present. Although historical data on the presence of seagrass does exist, it is limited and does not appear to be accurate. The world atlas of seagrasses states that in the Solway Firth, seagrass covers 2km^2 (Hily et al., 2003), however this estimate is made from a study which only surveyed the Scottish side of the Solway (Hawker, 1993). Two datasets show points of historical seagrass occurrence in the English Solway. The data from UNEP-WCMC[4] (2021) shows one point near the English-Scottish border, near to the Robin Rigg Offshore Wind Farm. It is highly unlikely that there is seagrass at this location due to the unsuitable water depth. The second data point is from seagrass observations data available in the EurOBIS database, downloaded from EMODnet Biology (2022). The data shows a historical point in the inner Solway on the border at Gretna, however it may in fact be referencing *Salicornia* spp. rather than seagrass. A report by Green et al. (2021) on the historical loss of the UK's seagrass, cites the attempts made by Butcher in the 1930s, to map distribution of seagrass around the UK. These maps show seagrass to seemingly occur ubiquitously around the coast including within the North and inner Solway. These reports do not provide any spatial estimates of seagrass extent.

The Environment Agency's Seagrass Potential Restoration Mapping exercise on the ReMeMarRe project did highlight areas of the inner Solway as potentially suitable for seagrass restoration. This mapping was based on wave and current energy, evaluation and salinity criteria. It does not take into account the levels of sediment in the water, which is particularly high in the inner Solway.

Regardless, it is not thought to be desirable or feasible to introduce seagrass where the historic presence or extent is unknown (pers. comms Jayes, A). There is a general lack of evidence and data on seagrass presence in the North West of England (pers. comms Unsworth, R). Without any historical data on location and extent of seagrass in the Solway on the Cumbrian side, it is recommended that any focus of seagrass work should be on locating and mapping what we already have, monitoring this for a long period of time and seeing if any further protection or reinforcement work is required.

Native oyster reefs are also considered as a highly valuable natural capital asset. Whilst there are ~~a~~ two data points showing the historical presence of native oysters in the outer Solway, a lack of data showing the extent of oyster beds in the area make restoration unfeasible and unlikely to be a priority here. The Scottish side of the Solway has one of the largest remaining natural native oyster fishery in the UK and is a more appropriate site to focus efforts for enhancement and restoration work.

6 Logic chains

Using Natural England's natural capital logic chain as a template, an assessment of the saltmarsh natural capital asset was completed using the available data. Data gaps and limitations are highlighted where relevant throughout.

[4] United Nations Environment Programme- World Conservation Monitoring Centre

6.1 Saltmarsh logic chain

1.1.1 Ecosystem asset:

Saltmarshes form on sheltered coasts, where intertidal mudflats become vegetated with a limited number of halophytic (salt-tolerant) plants. They are periodically covered by the tide and the differences in degree, and frequency, of inundation across the saltmarsh results in clear zonation. At the lower transition zone, either where there is frequent inundation by the tide or along the sides of creeks and pans, pioneer saltmarsh forms. Annual species such as marsh samphire (*Salicornia europaea*) colonise and dominate intertidal mudflats and sandflats. The pioneer marsh stabilises sediment allowing more stable vegetation to develop. Atlantic salt meadow vegetation then make up the mid- and upper saltmarsh. These communities are more species rich and tend to be dominated by perennials that can only withstand occasional inundation. Species found within this zone include cordgrasses (*Spartina* spp.), sea purslane (*Halimione portulacoides*), sea aster (*Aster tripolium*) and sea lavender (*Limonium vulgare*). Creeks form between the vegetated sediment, channelling water throughout the saltmarsh. Saltmarshes are naturally dynamic going through cycles of erosion and accretion.

The presence and function of a saltmarsh are influenced by ecological, hydrodynamic and sedimentary processes that operate in an intertidal 'accommodation space' (the area suitable for a saltmarsh to develop). This space lies approximately between the level of high-water neap tide and the highest astronomic tide. The lateral boundary is defined by unvegetated mudflats and sandflats. The landward extent of saltmarsh is limited by tidal flooding where brackish water, or freshwater marsh, vegetated shingle, or sand dunes may be present.

Saltmarshes provide a wide range of valuable benefits to humans, some of the most important being: habitat creation, climate regulation and flood and coastal risk management (Hankin et al., 2018). They are also important for erosion control, biodiversity maintenance and cultural services.

6.1.1 Saltmarsh quantity and location

The inner Solway Firth is fringed by 60km of grazed, coastal saltmarsh, extending from Skinburness to the River Esk at the Scottish border (Figure 8). There are significant areas of both pioneer saltmarsh and Atlantic salt meadows. The Solway's saltmarshes are internationally important, due to their extent and because they show the full transition from pioneer marsh to mature 'upper marsh', which is rarely seen elsewhere (Natural England, 2015). The upper marsh communities are particularly important because in many other UK estuaries they have been lost to land reclaiming and overgrazing.

The area of the Solway coast covered by saltmarsh is approximately 2,900ha. A total of 13% of the UK's Atlantic salt meadow occurs within the Solway Firth (both on the Scottish and English side), making them some of the largest areas of this important habitat (Natural England and Scottish Natural Heritage, 2010).

The entire area of the coast covered by saltmarsh lies within the boundaries of the Solway Firth SPA and SAC, the Solway Firth MCZ and the Upper Solway Flats and Marshes SSSI. Much of the saltmarsh (2,694ha) also lies within the Solway Coast AONB. The marshes qualify under the Habitats Directive as Annex 1 Habitats, as well as being qualifying interest features in the Solway Firth SAC and Upper Solway Flats and Marshes SSSI. The most

extensive areas of marsh on the English side of the estuary are Rockcliffe and Burgh Marshes and the marshes of Moricambe Bay.

Saltmarsh Location

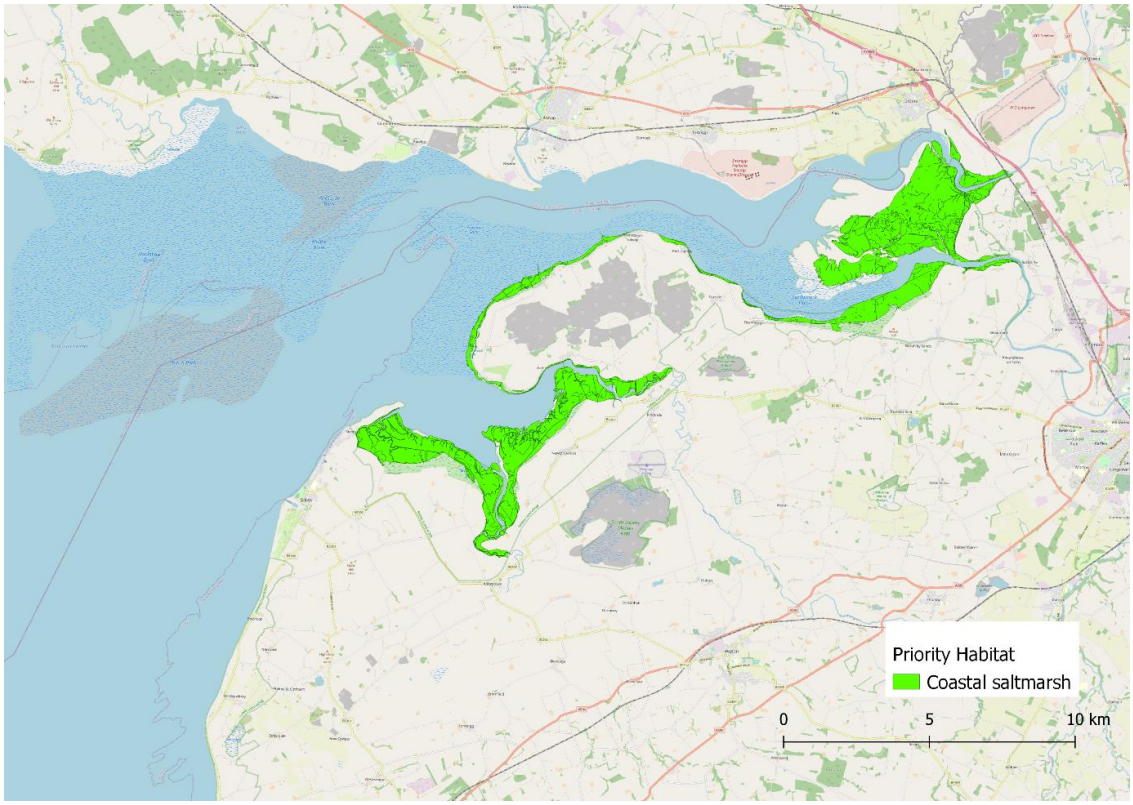

Figure 8 The geographic extent and location of saltmarsh on the English side of the Solway Firth. Data is from Natural England's Priority Habitats Inventory dataset. © OpenStreetMap contributors. Data is available under the Open Database License

6.1.2 Saltmarsh quality

6.1.2.1 What are the quality indicators for saltmarsh?

Direct indicators of saltmarsh quality come from measuring the structure and composition of the saltmarsh habitat. The following indicators are used to monitor the condition of saltmarshes within designated sites:

- Habitat extent
- Physical structure: creeks and pans
- Vegetation structure: zonation and sward structure
- Vegetation composition: characteristic species; indicators of negative trend (*Spartina anglica*)
- Other negative indicators (disturbances such as new artificial drains, visual pollution, turf cutting, vehicle damage or trampling at vulnerable locations).

(JNCC, 2004)

Indirect indicators of saltmarsh quality relate to the environmental conditions within the saltmarsh habitat, for example, nutrient levels and grazing regimes.

6.1.2.2 Measuring condition of saltmarshes using the Water Framework Directive method

The Water Framework Directive (WFD) requires measures to be taken to get all water bodies to Good Ecological Status (GES) by 2027. To reach GES a water body must meet a range of biological and chemical quality standards. One of the biological quality elements assessed for transitional and coastal waters is Angiosperms/Saltmarsh. A tool for assessing whether saltmarsh is at GES was published by UKTAG in 2014. This saltmarsh index tool was designed to detect impacts from hydro-morphological pressures, such as those that alter a water body's physical structure and flow characteristics that arise from activities such as sediment transport, navigation, flood protection, and to a lesser extent, increased nutrient concentrations (eutrophication).

The saltmarsh index is based on:

- saltmarsh extent (current proportion of historical extent and extent change);
- proportions of zones present;
- dominant zone extent as a proportion of the total extent; and
- number of taxa as a proportion of a historical reference.

These measurements are combined to derive an 'Ecological Quality Ratio'.

(Miles and Richardson 2018)

An assessment of WFD saltmarsh status in England was carried out in 2016 (Miles and Richardson 2018). Saltmarsh in the Solway Firth received an overall rating of 'Good' (Table 8)

Table 8 Water Framework Directive assessment of saltmarsh status for the Solway Firth.

	Saltmarsh extent as a proportion of "historic saltmarsh"	Saltmarsh extent as a proportion of intertidal area	Change in saltmarsh extent over two or more time periods	Proportion of saltmarsh zones present	Proportion of saltmarsh area covered by the dominant saltmarsh zone	Proportion of observed taxa to a historical reference value or proportion of observed taxa to 15 taxa	Final
Status	Good	Moderate	High	High	Moderate	High	Good

Progress against the UK target on saltmarsh quality was assessed for the Celtic Seas and the Greater North Sea Marine Strategy Framework Directive[5] sub-regions and their constituent UK Regional Seas in 2018. However, within the Celtic Sea MSFD sub-region, five out of the six UK Regional Seas were not assessed, including the Irish Sea region, which includes the Solway Firth. This was due to a lack of data required for the WFD classification (Phillips et al., 2018).

[5] This is now assessed under the UK Marine Strategy which was updated in 2019 to replace the Marine Strategy Framework Directive after the UK's departure from the EU.

6.1.2.3 Condition of Upper Solway Flats & Marshes SSSI

Overall, 99.74% of the Upper Solway Flats & Marshes SSSI is in 'favourable' or 'unfavourable- recovering' condition (Natural England, 2022). The areas of the SSSI in 'unfavourable-no change' condition, do not contain saltmarsh habitat. And none of the site is in 'unfavourable-declining' condition.

6.1.2.4 Habitat extent

Saltmarshes are dynamic systems and will accrete or erode in response to changes in climate, or wind and wave energy. The amount of offshore sediment available can determine how the system responds to these changes. Anthropogenic activities, such as dredging or the introduction of hard sea defences and structures like sea walls, can impact upon the volume of sediment that enters the system. A balance of accretion and erosion within a system is seen as favourable, however, erosion alone causes a loss of habitat extent.

The Environment Agency has mapped the changes in the extent of saltmarsh across England since baseline surveys completed between 2006 to 2009 (Figure 9). The Solway's saltmarshes have accreted overall, with a net increase of 50.2ha of saltmarsh. This is due to significant accretion of saltmarsh on the edges of Rockcliffe Marsh. Sediment is being carried into the system by the rivers Esk and Eden, building up on the edges of the saltmarsh and causing it to expand seawards. Landward expansion of the saltmarsh is limited at this site by the in-land seawall.

Recommendation

Continue to monitor accretion and erosion of the Solway's saltmarshes

Saltmarsh Extent Change

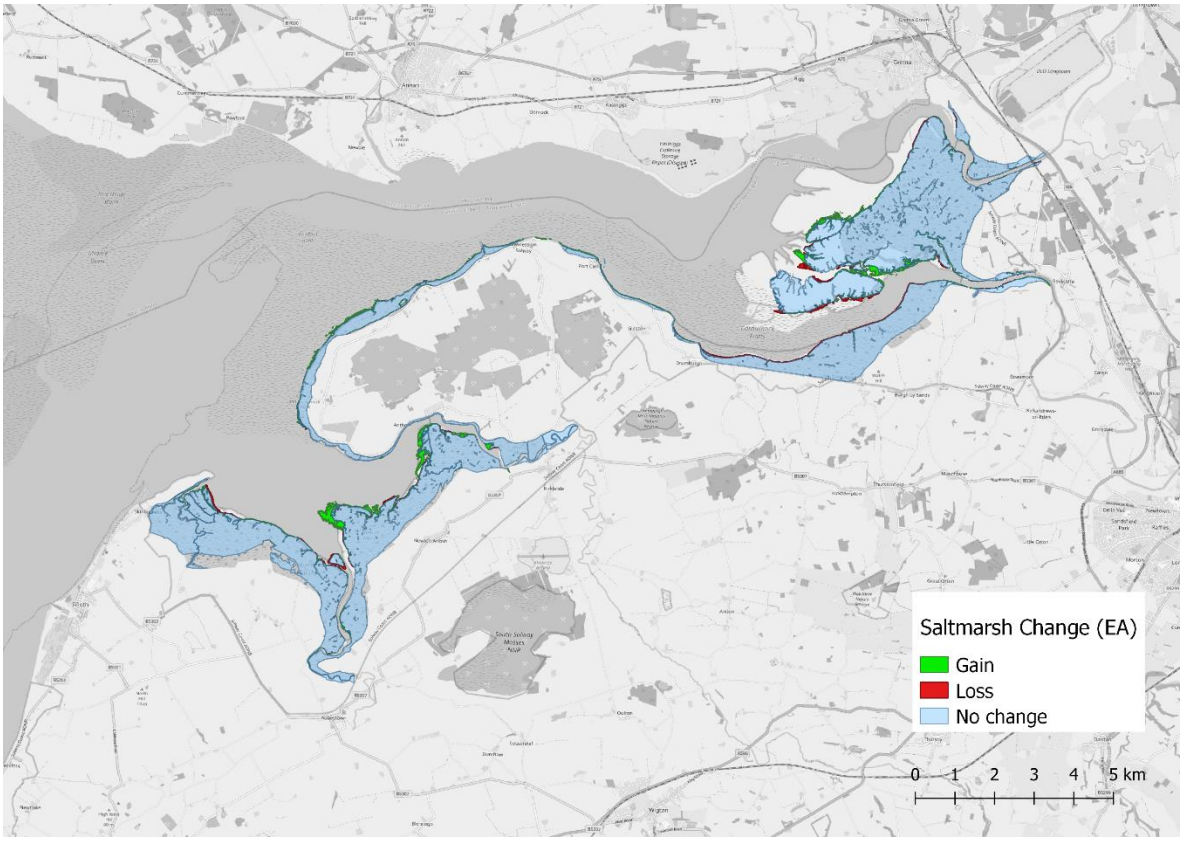

Figure 9 The saltmarsh change layer created by the Environment Agency shows the recent gains and losses in saltmarsh extent across England since a baseline survey was completed between 2006 to 2009. © Environment Agency copyright and/or database right 2015. All rights reserved. © OpenStreetMap contributors. Data is available under the Open Database License

6.1.2.5 Physical structure

Creeks and pans (also known as salt pools or marsh ponds) of varying size and number are an important feature of a saltmarsh; they absorb tidal energy, deliver sediment into the saltmarsh and allow pioneer species to establish on their banks higher into the saltmarsh system. Anthropogenic alterations to creek patterns or loss of pans will alter the efficiency of these processes. Changes in creek patterns and pans can be assessed compared to a baseline by using aerial photographs and remote sensing. This information is often collected by Natural England as part of their designated area condition assessment.

Solway's marshes have an interesting geomorphological structure created by the saltmarsh forming as the land moves in relation to the sea, known as isostatic adjustment. The terraced structure provides breeding pools for the rare natterjack toad, with more than 10% of the UK's breeding population being supported by the Solway's saltmarshes (Natural England and Scottish Natural Heritage, 2010).

6.1.2.6 Vegetation structure

Zonation:

Saltmarsh zonation patterns can vary depending on the region and site however, a natural saltmarsh should have distinct zones from the pioneer zone, low-mid marsh, mid-upper marsh and transitions to terrestrial habitat. Natural zonation can be limited by previous land reclamation which prevents natural transitions to terrestrial communities.

The saltmarsh in the Solway Firth has been identified as being of international importance because it represents some of the only saltmarshes in the country that has the full transition across the zones from pioneer to the upper marsh. However, the Upper Solway Flats and Marshes SSSI condition assessments note that multiple units have little seaward zonation due to erosion and consequently no lower or pioneer marsh. Other areas are reported to have no landward zonation due to the presence of the coastal road.

The Environment Agency has mapped the percentage area of each saltmarsh zone (Figure 10). From this data, we can see which areas of the Solway Firth have all the saltmarsh zones and which areas are lacking the lower zones characterised by pioneer species.

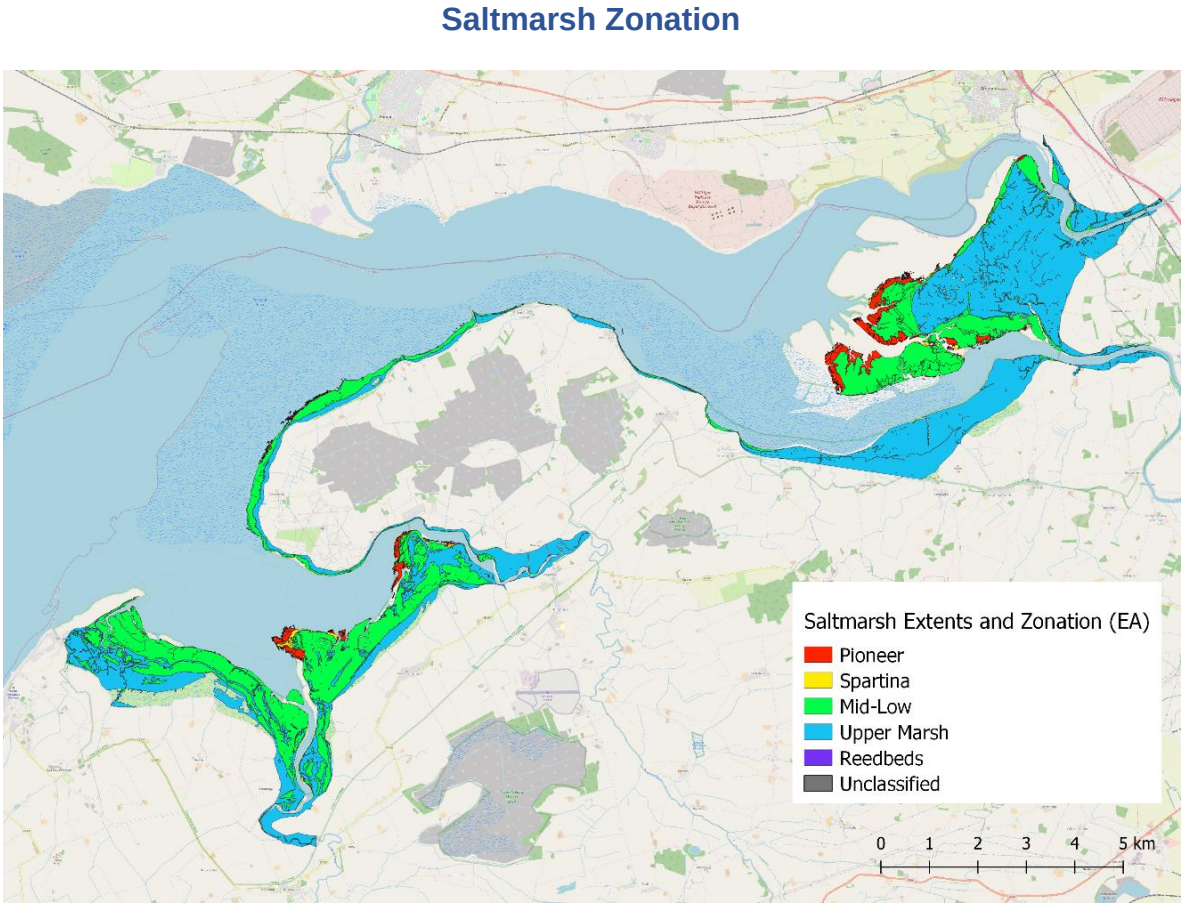

Figure 10 The Environment Agency's Saltmarsh Extent and Zonation layer mapped from aerial photographs collected between 2006 and 2019. The mapped extent and zonation have been ground--truthed with data collected by the Environment Agency and Natural England. © Environment Agency copyright and/or database right 2015. All rights reserved. © OpenStreetMap contributors. Data is available under the Open Database License

Sward structure:

Varied vegetation structure is important for maintaining invertebrate and bird diversity. Each bird species that use the saltmarsh, has different preferences in sward height. Close-cropped swards are favoured by specific bird species which are important to the area such as breeding oystercatcher and overwintering ducks and geese. For example, the Svalbard barnacle geese preferentially graze a sward height of 2-4cm (NE and SNH, 2010). However, wading bird species such as lapwing and redshank, prefer longer vegetation for nesting. It is therefore important to maintain a varied vegetation structure so the marshes can continue to support diverse bird populations.

Sward structure is impacted by community type, grazing type and level. Sheep are more selective than cattle and bite off vegetation close to the soil, this creates a more closely cropped sward. Cows are less selective and use their tongues to rip up vegetation from the sward, this creates a more varied sward structure. These differences in grazing technique results in different sward heights. Managing grazing of saltmarsh correctly can be difficult and will depend on the site and the interest features being protected, however, maintaining structurally diverse vegetation is advantageous as it provides habitat for a range of bird species and maintains invertebrate diversity (NE and SNH, 2010).

6.1.2.7 Vegetation composition

Unlike marshes on the south coast of England, saltmarshes in the Solway develop on sandy sediment. The species composition that these saltmarshes support is important, because it represents the northernmost limit for many species. The Solway is the northern limit for many of the marsh's plant species such as sea purslane (*Atriplex portulacoides*), common sea lavender (*Limonium vulgare*) and lax-flowered sea lavender (*Limonium humile*) (Natural England and Scottish Natural Heritage, 2010).

Negative indicator species - Spartina anglica:

The cordgrass *Spartina anglica* is an invasive species that can impact the intertidal mudflats, pioneer and lower-mid saltmarsh communities. *Spartina anglica* can become a problem when it rapidly expands and negatively impacts upon the mudflat's pioneer saltmarsh Annex 1 features.

Data on the occurrence of *Spartina anglica* on the Solway varies between different sources. Lush et al. (2016), report several records of *Spartina anglica* on the Solway within the Upper Solway Flats and Marshes SSSI and the Solway Firth SAC. The NBN Atlas records show just one site on the Cumbrian side of the Solway, near Skinburness. However, the most recent condition assessment of the Upper Solway Flats and Marshes SSSI only records its recent appearance at Campfield marsh *'Only cause for concern is the recent appearance of Spartina which is now starting to colonise the Solway.'* (Natural England, 2022). The presence of *Spartina anglica* may not be as negative as once thought or considered as a negative indicator (pers. comms Browning, L.)

6.1.2.8 Nutrient enrichment

Saltmarshes play an important role in regulating water quality by absorbing and storing excess inorganic nutrients (e.g. phosphates and nitrates), heavy metals, and other pollutants from the water. They can also reduce faecal organism concentrations, improving water quality. Saltmarshes are often exposed to high levels of a variety of pollutants from nearby agricultural land (Möller et al., 2021). Poor water quality, particularly from high nutrient levels, can impact the quality and resilience of saltmarshes.

Nutrient enrichment of saltmarshes can reduce the presence and abundance of key upper-marsh species altering the community composition (Haynes, 2016). Nutrient enrichment can also cause excess macroalgal blooms, in certain circumstances this may lead to smothering of marsh vegetation (Hayes, 2016). Signs of historic nutrient enrichment mean that some units of the Upper Solway Flats and Marshes SSSI are in unfavourable condition (Natural England, 2017).

6.1.2.9 Grazing

There have traditionally been high levels of grazing in North West England and this has had a long-term influence on the marsh's vegetation structure and species compositions. Much of the Solway's saltmarshes are heavily overgrazed with high stocking densities year-round of both sheep and cows in spring and summer, and grazing wildfowl over winter. Typically, the higher the grazing intensity, the less structural diversity is present. Heavy grazing can also prevent the growth of rare and grazing-sensitive species and favour competitive tillering grasses (e.g. *Puccinellia* spp.), generally resulting in lower species diversity. However, under-grazing can reduce plant diversity by competitive exclusion.

The Saltmarsh Management Manual summarises the main impacts associated with grazing as follows:

- reduced sedimentation
- decreased species richness where stocking levels are high
- spread of lower saltmarsh plant communities into the higher saltmarsh
- vegetation patterns differ between high and low stocking densities
- reduction in populations of detritus-feeding invertebrates and their predators due to reduced production of vegetation litter
- reduced migration of invertebrates from upper to lower marsh
- reduction of plant-feeding insect species because of removal of the higher vegetation canopy
- reduction in the marsh's surface roughness can reduce the marsh's sea defence value
- improved habitat for grazing wildfowl

(Adnitt et al., 2007)

Grazing management of saltmarshes needs to consider the value of interest features at the site. The Solway Firth is an internationally important site for Svalbard barnacle geese, supporting the entire population over winter. The grazing on much of the saltmarshes is therefore managed to keep close-cropped vegetation, which benefits the geese.

> Recommendation
>
> Research how the condition of the Solway's natural capital assets impacts their value.

6.1.3 Ecosystem service flows

The short-list ecosystem services identified by Natural England (Lusardi et al., 2020), are discussed below.

*6.1.3.1 Ecosystem service flows: **mass stabilisation** (i.e. erosion control)*

Saltmarshes trap and retain sediment from the water column around their root systems in a process called accretion. Accretion allows the saltmarsh to expand its extent or to build-up height. If saltmarshes are supplied with enough sediment to accrete at a rate that can keep up with sea level rise, then they will be able to stay above the water, helping to prevent flooding or loss of the coastal buffer through erosion. The ability of saltmarsh to provide mass stabilisation is impacted by sediment supply and vegetation cover compared to bare soil (i.e. the dynamic between saltmarsh and mudflats). Saltmarsh provides £4,019 per ha cost savings in terms of coastal control and storm buffering, equating to £4.58 billion across the UK (Beaumont et al., 2014, cited in Environment Agency, 2017).

Erosion risk for the Inner Solway is low, with very little coastal retreat predicted by 2055 around areas of saltmarsh (Figure 11). However, this may also be because there is less wave and tidal impacts where saltmarsh has formed.

Predicted rates of coastal erosion

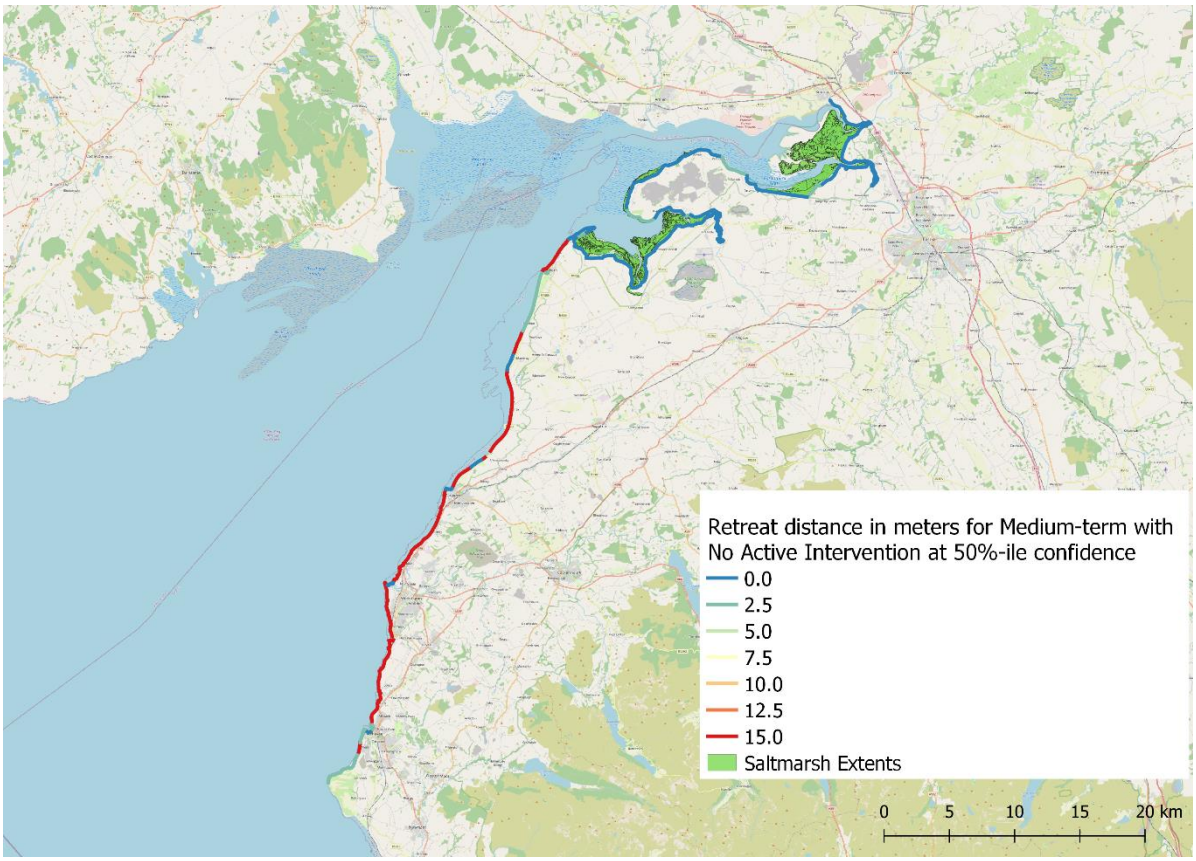

Figure 11 Predicted erosion rates in meters for the medium term (up to 2055) with Shoreline Management Plan Strategy 'No Active Intervention' ('no planned investment in defending against flooding or erosion') at 50 percentile confidence. Data from the Environment Agency, 2022). © OpenStreetMap contributors. Data is available under the Open Database License

*6.1.3.2 Ecosystem service flows: **flood protection***

Saltmarshes and their associated mudflats, reduce wave and tidal energy, acting as a buffer between the sea and land, reducing the impacts from storms, floods, tidal surges and waves. The UK National Ecosystem Assessment (2011) calculates that the monetary value of existing natural sea defences around the UK to be £4.05 billion, half of which is from saltmarsh (Environment Agency, 2017).

The Solway's saltmarshes are already functioning as flood defence and could be enhanced or expanded to allow this service to continue as sea levels rise. Cumbria's Coastal Strategy suggests capitalising upon the extensive areas of saltmarsh along the inner Solway. With the suggested strategic approach for Moricambe Bay and Cardurnock to the Scottish Border being environmental enhancement; allowing the saltmarsh to continue to function as a natural sea defence and enhance this by creating a more natural coastline where possible.

6.1.3.3 Ecosystem service flows: ***maintenance of nursery populations and habitats***

Vegetated intertidal zones are important for fish species and can be highly productive compared to subtidal areas (Colclough et al., 2003). Saltmarsh creeks, channels and pools of standing water, provide a nursery ground for juvenile fish and shellfish. The marsh provides refuge from predators and areas of foraging (Colclough et al., 2003). Larger predatory fish will avoid entering the marsh as it is often too shallow for them to risk being stranded or preyed on by birds. Research on the use of saltmarsh by fish is limited, with few studies in Europe. However, as more managed realignment projects happen, more fish sampling in saltmarshes is being carried out (Colclough et al., 2003).

A total of 130 species of fish have been recorded in the Solway Firth (Potts and Swaby, 1993). A study by Coul et al. (1998) of 14 commercially important fish species, later updated by Ellis (2012) to include 40 species, identified the Solway as an important spawning and nursery ground for commercially important species. Sprat (*Spratus spratus)* is the only species identified in these studies to use the inner Solway to spawn. However, the inner Solway is an important nursery ground for herring, whiting and cod (Ellis, 2012). It also provides a nursery ground for thornback ray, sole, sand eel, plaice, anglerfish and tope, but in lower numbers (Ellis, 2012).

Post-larval brown shrimp (*Crangon crangon*), a commercially important species in the inner Solway, also use the creeks and channels of the saltmarsh to forage and avoid predation (Cattrijsse et al., 1997).

Estuaries provide important feeding and nursery habitat for European smelt (*Osmerus eperlanus*). Smelt migrate into freshwater to spawn, then return back towards the coast, staying in the inner estuary until the following winter (Scholle et al., 2007). Historically, there was a productive smelt fishery in the Solway Firth, but populations have since crashed. The Solway Firth MCZ was designated in 2019 for the protection of smelt populations. Nekton (like juvenile fish) survival can be greater in saltmarshes than in open water (Minello et al., 2003). Therefore, protecting and enhancing saltmarshes could support juvenile smelt, increasing recruitment into the adult population. It is likely that there is less habitat available in sites with heavy grazing as less shelter and protection from vegetation is available. Additional data on juvenile fish use of the Solway's saltmarshes would allow a value to be calculated for the natural capital asset, and therefore the value of habitat restoration in relation to maintaining nursery grounds for commercially important fish species.

Studies of restored intertidal saltmarsh show juvenile fish using the marshes (Colclough et al., 2005). Fish species observed included European smelt (*Osmerus eperlanus*), sand-smelt (*Atherina presbyter*), sea bass (*Dicentrarchus labrax*), flounder (*Platichthys flesus*), dace (*Leuciscus leuciscus*), roach (*Rutilus rutilus*), common goby (*Pomatoschistus Microps*), sand goby (*Pomatoschistus Minutus*), eel, herring (*Clupea harengus),* three spined stickleback (*Gasterosteus aculeatus*), thick-lipped mullet *(Chelon labrosus*) and thin-lipped mullet (*Chelon ramada*). Fish were observed to be positively associated with stands of vegetation and habitat heterogeneity. Semi-permanent bodies of water at low tide were also found to be important in supporting high species richness. These wet areas at low tide provide continuous refuge and food for young fish. European smelt were observed using the vegetated terraces at Millennium Terraces (a site in the Tames Estuary where managed realignment has taken place).

Recommendation

Improve our understanding of how European smelt and other juvenile fish use the Solway's saltmarsh

*6.1.3.4 Ecosystem service flows: **climate regulation***

Saltmarshes are recognised for their vital role in climate regulation as they can sequester more carbon per unit area than any other coastal ecosystem (Stafford et al., 2021). Healthy, accreting saltmarsh even rivals terrestrial habitats, sequestering almost 10 times the amount of carbon compared to terrestrial forests of an equivalent areal extent (Mcleod et al., 2011).

Not only do they draw carbon from the atmosphere, but they also fix this carbon into the sediment below, down to depths of 8m. As sediment is brought in by the tide, it buries and traps layers of decomposing vegetation, this carbon-rich organic matter is buried deep in the system as each tide brings in more layers of sediment. The majority of carbon is stored in the sediment (average of 56t C ha^{-1}) but it is also stored in the vegetation (average of 0.6t C ha^{-1}) (Gregg et al., 2021).

Healthy saltmarsh in the UK can sequester carbon in the range of 2.35 to 8.07t CO_2 ha^{-1} yr^{-1}, with typical figures around 4.40–5.50t CO_2 ha^{-1} yr^{-1} (Stafford et al., 2021). Using the mean value (4.95t CO_2 ha^{-1} yr^{-1}), the levels of carbon sequestered each year by the Solway's saltmarshes can be estimated. The level of carbon stored can also be estimated using values from Gregg et al. (2021). The value of this can then be valued based on the non-traded price of carbon of £68t^{-1} (2019 prices from BEIS, 2019) (Table 9). The non-traded value of carbon is predicted to increase in the future, projected to reach £230t^{-1} of CO_2 by 2050 (BEIS, 2019).

Table 9 The calculated value of carbon stored and sequestered in the Solway's saltmarshes (based on Environment Agency's extent of 2987.4ha)

	Tonnes	Value
Carbon stock vegetation	1792	£ 121,886
Carbon stock sediment	167,294	£ 11,376,019
Carbon stock combined	169,087	£ 11,497,905
CO2 sequestered per year	14,788	£ 1,005,559

The carbon sequestration and storage rates at restored saltmarshes have been studied in the UK at sites where managed realignment has taken place, such as the Wildfowl and Wetlands Trust's Steart Marshes (Mossman, et al., 2021). The development of a saltmarsh carbon code would allow the carbon storage potential of a site to be realised, this will help to measure the value of habitat creation through managed realignment.

Recommendation

Collect empirical data on the carbon sequestration and storage rates of the Solway's saltmarshes

*6.1.3.5 Ecosystem service flows: **cultural services***

The links between ecosystem services from marine and coastal habitats and human wellbeing-related benefits is less widely understood and generally understudied (Rendon et al., 2019). The benefits from saltmarshes with the most linkages to human-wellbeing are improved health, connection to nature and living standards (Rendon et al., 2019). The Solway's saltmarshes and mudflats typically attract visitors who are interested in natural history, with bird watching being particularly popular. As bird watching is a free recreational activity, its value is difficult to estimate.

There is limited public awareness around the societal benefits of saltmarshes (McKinley et al., 2020). There is a need to improve public knowledge and understanding of saltmarshes and their benefits to society and the wider ecosystem.

Recommendation

Research how local communities' value marine and coastal natural capital assets

*6.1.3.6 Ecosystem service flows: **water quality***

Water quality was not a short list ecosystem service in Natural England's Indicators work for any coastal asset. However, it was a priority benefit for stakeholders and therefore, it will be discussed in greater detail here.

Saltmarshes can play an important role in regulating coastal water quality by acting as a sink for contaminants entering the estuary from human activities such as agriculture. A significant proportion of pollutants are adsorbed onto sediment particles which are then deposited into saltmarsh systems and buried by accretion. This removes the pollutants from the water and over time they become inactive and unavailable, reducing the effects on marine and coastal organisms. Improved water quality benefits other marine and coastal habitats, as well as species such as seagrass and native oysters. Erosion of saltmarsh sediment and other changes to sediment dynamics can lead to the release and re-deposition of pollutants.

Saltmarshes also play a crucial role in nutrient cycling, controlling levels of nutrients that are important indicators of water quality and human health. For example, saltmarshes export nitrogen and, in smaller amounts, phosphorus, into the wider coastal environment.

Recommendation

Increase our understanding of the ecosystem services provided by the Solway's marine and coastal assets

6.1.4 Drivers of change and pressures

The following have been identified as having the potential to cause deterioration or disturbance to saltmarsh habitats with the Solway SAC and SPA (Natural England and Scottish Natural Heritage, 2010). Saltmarshes are sensitive to:

- Removal or smothering activities such as coastal development, land claim or the creation of physical barriers such as sea walls, preventing inland migration as a response to sea level rise and resulting in coastal squeeze.
- Physical damage through abrasive activities such as bait collection can uproot plants and destabilise mudflats on which *Salicornia* species grow.
- Changes in siltation patterns that affect the formation of pioneer saltmarsh.
- Damage through overgrazing or under-grazing, affecting saltmarsh diversity and structure.
- Recreational activities, such as the use of vehicles on saltmarsh, that damage the vegetation structure.
- Toxic contamination that impacts upon the ecosystem and can bioaccumulate in vegetation, causing impacts up the food chain.
- Invasive species, such as the cordgrass *Spartina anglica* that compete with pioneer, lower and mid-saltmarsh species.
- The impacts of climate change such as sea level rise and increased storm events.

6.1.4.1 Climate change

The Upper Solway Flats and Marshes SPA has been identified by Natural England as being the SPA most at risk from climate change and the Solway Firth SAC is one of the 10 SACs considered most at risk to the impacts of climate change (Miles and Richardson, 2018). Saltmarshes are sensitive to climate change, particularly the impacts of sea level rise and storm events, these impacts will be exacerbated by the creation of hard sea defences (Natural England and RSPB, 2014). However, saltmarsh habitats are adaptive systems, and if given the space and a sufficient supply of sediment, they should be able to adapt to rising sea levels, by accreting vertically or moving landward (Mossman et al., 2013). Therefore, the threat of sea level rise can be minimised if saltmarshes are given the conditions they need to naturally adapt.

Where accretion rates cannot keep up with sea level rise, the saltmarsh could experience increased levels of inundation by the tide and water-logging of sediments, this will alter community composition. The construction of hard sea defences reduces the area available for saltmarsh to migrate landward, resulting in coastal squeeze, and may alter sediment dynamics, adding to the deterioration of the marsh.

As such, predicted sea level rise needs to be taken into consideration when planning for habitat restoration or enhancement, as well as any planned hard sea defences. There is no point in restoring or creating habitats in areas that will be underwater within the next few decades. Instead, habitats should be given the opportunity to be dynamic and adapt to changes by being allowed the space to move landward and accrete vertically. Much of the coast along the inner Solway is predicted to be below the annual flood level by 2100. This flooding needs to be planned for, however, it could create an opportunity to expand intertidal habitats in areas where physical barriers, such as topography or coastal roads have limited their extent.

Increasing temperatures and drier summers will also change the conditions within the marsh, reducing the suitable habitat space and altering community composition. Other changes could include increased erosion and runoff on adjacent agricultural land that could increase nutrient levels and change the community composition of the saltmarsh (Natural England and RSPB, 2014).

6.1.5 Potential

Several techniques for managing and enhancing saltmarsh have been developed (see the Saltmarsh Management Manual (Adnitt et al., 2007). As part of the ReMeMaRe project, the Environment Agency have published a Saltmarsh Restoration Handbook (Hudson et al., 2021) that provides a detailed review of each stage of the process of restoring saltmarsh.

There is a significant potential to restore the quality of the Solway's saltmarshes. The main ways for improving the value of the Solway's saltmarshes, identified through consultation with stakeholders, are to:

1. Follow the Shoreline Management Plan and Cumbria's Coastal Strategy to reduce the risk of coastal squeeze and implement habitat creation through managed realignment or regulated tidal exchange.
2. Apply the enhancement techniques used to restore saltmarshes at Rockcliffe and Campfield Marshes to other sites.
3. Improve saltmarsh quality by making changes to grazing management.

6.1.5.1 Habitat restoration/ creation

There are two main techniques for saltmarsh restoration that could be suitable for the Solway, as suggested in the Cumbria Coastal Strategy:

- Managed realignment; and
- Regulated tidal exchange

Managed realignment is the deliberate breaching of sea defences resulting in managed flooding up to a new line of defence. This method creates space for new intertidal habitats to develop, replacing that which may have been lost due to erosion and coastal squeeze. The new saltmarsh and intertidal mudflats can then act as a natural buffer between land and sea, reducing the impacts of sea level rise and storm surges on coastal communities. Managed realignment can have significant economic advantages as it reduces the cost of flood defence maintenance and the adaptive natural defence provided by the saltmarsh can result in long-term savings.

Several projects have identified sites that may be suitable for coastal habitat creation through managed realignment (Table 10).

Regulated tidal exchange refers to the creation of saltmarsh or other intertidal habitats behind sea defences using pipes or sluice gates to allow tidal flushing. This method allows controlled water levels to flood new areas.

Cumbria Coastal Strategy

The long-term Shoreline Management Plan for the inner Solway area is to allow natural evolution of the coast, allowing future sea level rise to return low lying areas to saltmarsh. Managed realignment will enable proactive adaption and opportunities for habitat creation. None of the Solway's priority units (stretches of coast for which a shoreline management policy has been set) have habitat creation recommended as a strategic approach. However, several of the non-priority units between Moricambe Bay and the Scottish border, suggest environmental enhancement as the best approach.

Sites with habitat enhancement or creation suggested as a preferred strategic approach are included in Table 10.

Table 10 Shoreline Management Plan policy units where the Cumbria Coastal Strategy's preferred strategic approach includes opportunities for saltmarsh enhancement, expansion or habitat creation. The preferred strategic approaches are colour coded. Monitoring of the marsh and considering future realignment. Potential for habitat enhancement. Potential for natural expansion of marsh habitat. Potential for habitat creation.

Location	Preferred strategic approach
11e7.2 Skinburness to Wath Farm	Hold the line
11e7.3 Wath Farm to Saltcoates including Waver to Brownrigg	Managed realignment
11e7.4 Newton Marsh	No active intervention
11e7.5 Newton Marsh to Anthorn including Wampool to NTL	Managed realignment
11e7.6 Anthorn	Hold the line
11e7.7 Anthorn to Cardurnock	Managed realignment
11e8.1 Cardurnock to Bowness-on-Solway	Managed realignment
11e8.3 Bowness-on-Solway to Drumburgh	Managed realignment
11e8.4 Drumburgh to Dykesfield	Managed realignment
11e8.5 Dykesfield to Kingmoor (Eden Normal Tidal Limit)	Managed realignment
11e8.6 Kingmoor (Eden Normal Tidal Limit) to Rockcliffe	Managed realignment
11e8.9 Demesne Farm to Metal Bridge (Esk)	Managed realignment
11e8.10 Metal Bridge (Esk) to the River Sark	Managed realignment

Despite there being few formal hard sea defences along the inner Solway coast behind areas of saltmarsh, there is a coastal road that runs behind the marshes as well as areas where natural embankments are present. However, even if the coastal road was not present, the naturally raised topography, on top of which the road lies, acts as a physical barrier to saltmarsh migration. This limits opportunities for landward saltmarsh expansion. For a site to be suitable for saltmarsh to expansion, there needs to be a flatter and more gradual topography. The only area where this is the case is around Silloth and Skinburness (pers. comms Blackledge, D).

Recommendation

Investigate potential habitat restoration sites.

Habitat creation areas

The Marine Management Organisation (MMO) have produced data layers as part of the 'Identifying sites for habitat creation (MMO1135)' project, which maps potential habitat creation sites, including areas suitable for the creation or restoration of saltmarshes and mudflats. The data shows '*Currently defended floodplain areas in England which could be suitable for managed realignment and/or Regulated Tidal Exchange (RTE) (to create mudflats and saltmarshes).'* Potential sites were identified in the inner Solway behind areas of current saltmarsh (Figure 12). This mapping is intended to be used at the initial stages of a search for potential sites, but further research and consultation of local knowledge are necessary to confirm the suitability of a site (MMO, 2019).

The RSPB's Sustainable Shores Project (Miles and Richardson, 2018) built on the Seas of Change report (Pilcher et al., 2002), which mapped locations for potential coastal habitat creation. Two sites on the Cumbrian Solway were identified as priority opportunities (Figure 12). An area of 355ha of the English Solway was identified for intertidal habitat creation, this accounts for 15.6% of the area identified in North West England, making it the second largest area of potential intertidal habitat creation (after the Ribble estuary accounting for 57.5%) (Pilcher et al., 2002).

Sites were identified as potentially suitable for habitat creation if the inter-tidal habitat was deemed practical and not to entail excessive costs. Sites will need ground truthing before any action can be taken, and assessed on:

1. The physical nature of the site
2. Social and cultural considerations
3. Engineering considerations
4. Nature conservation considerations
5. Economic considerations

(Pilcher et al., 2002).

RSPB's Sustainable Shores - Potential Coastal Habitat Creation Sites

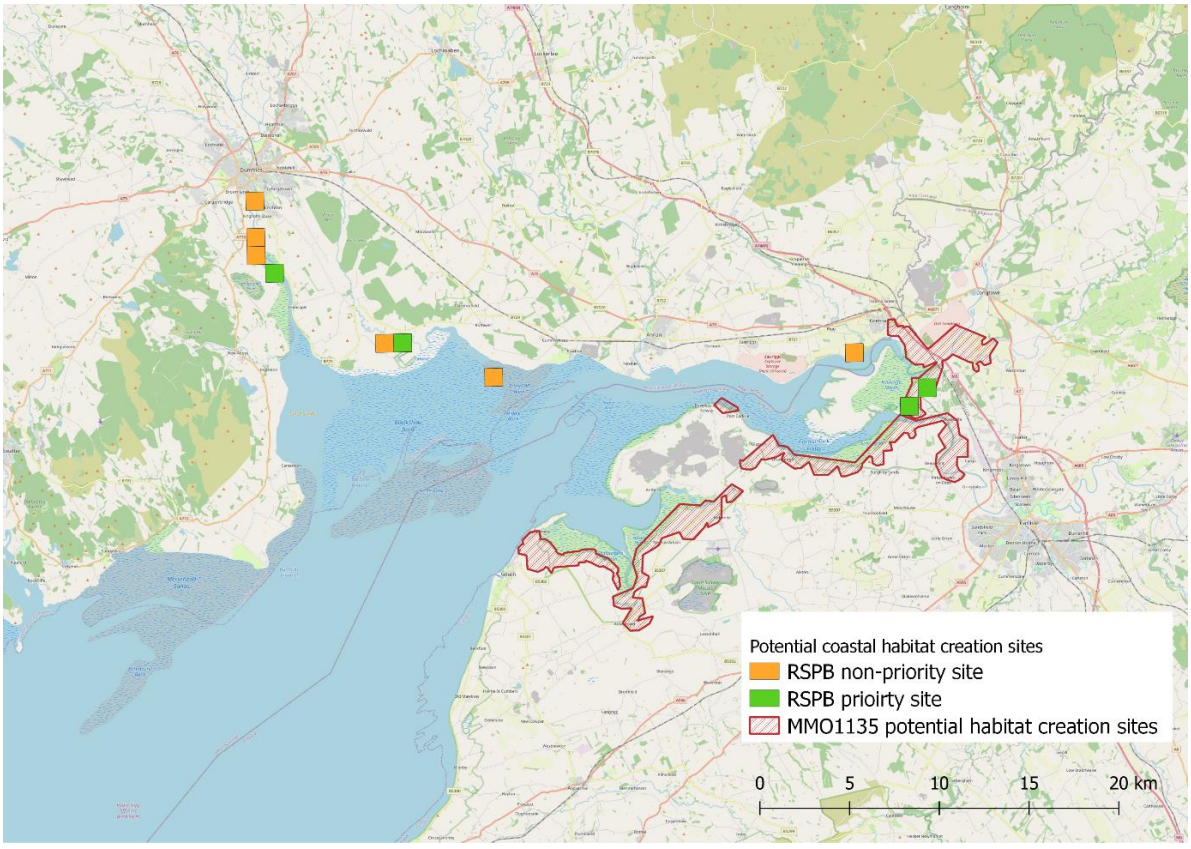

Figure 12 Sites identified by the RSPB's Sustainable Shores project and MMO's Identifying sites for habitat creation (MMO1135)' project as suitable for coastal habitat creation (Miles and Richardson, 2018). © OpenStreetMap contributors. Data is available under the Open Database License

The RSPB's Life on the Edge project identified protected coastal sites across Cumbria that would be suitable for enhancement, with the aim to improve habitat quality for breeding,

migrating and wintering water birds. None of the chosen target sites were in the Solway, however sites put forward during initial planning stages included those on the Solway coast. Habitat restoration that compliments existing projects such as these, would be most useful in restoring and enhancing the natural capital assets of the Solway.

LNRS enhancing the habitat network

Habitat maps created as part of the Cumbria Local Nature Recovery Strategy Pilot identify possible sites where saltmarsh could be expanded and where it could contribute to enhancing the habitat network. The mapping in the pilot highlights large areas of the Solway coast where expanding and restoring saltmarshes would contribute to a larger habitat network. The maps are available to view and download from the Cumbria Biodiversity Data Centre website.

The seaward area from Cardunock to North Plain has been suggested to have the potential for restoration (where existing habitats could be restored to a more wildlife-rich state). The maps also show the majority of both landward and seaward areas adjacent to current saltmarsh within the Solway as meeting the requirements of Network Enhancement Zone 1 – areas that could be targeted for habitat restoration or creation, helping to join-up habitat and create a nature recovery network.

Potential benefits of habitat restoration/creation

Restoring saltmarsh has the potential to increase the number of natural capital benefits provided by saltmarsh in the Solway. However, the ecosystem services provided by restored saltmarshes may not be equal to that of natural saltmarsh. For example, the levels of biodiversity enhancement at restored sites have been variable (Gregg et al., 2021).

The carbon sequestration rate of newly restored saltmarsh is up to 3.18t CO_2 $ha^{-1}y^{-1}$ for the first 20 years, this then plateaus to a rate of 2.38t CO_2 $ha^{-1}y^{-1}$. These rates are lower than typically seen in natural systems, likely because of differences in community composition (Stafford et al., 2021). Restoring 355ha of saltmarsh habitat, as suggested by the RSBP's Seas of Change project, could provide 1,128.9t CO_2 y^{-1} of additional carbon sequestered over the first 20 years' worth £76,765.20 each year based on the current non-traded value of carbon, after 20 years the restored marsh would contribute 844.9t CO_2 y^{-1} worth £57,453.20.

The creation of saltmarsh habitat through opportunities for managed realignment has the potential to have considerable long-term effects on the enhancement of commercial and non-commercial fish and shellfish species that use saltmarsh as a nursery ground. There is currently a lack of data available to estimate the value of saltmarsh restoration for fish stocks.

6.1.5.2 Enhancing saltmarsh quality

Rockcliffe Marsh – Castletown Estate, Natural England and Cumbria Wildlife Trust

Rockcliffe Marsh is one of the UK's largest areas of saltmarsh covering 1019 ha (Burge, 2021). It is situated at the head of the Solway Firth estuary between the River Esk and the River Eden. The site is privately owned by Castletown Estate and managed for key bird species and vegetation assemblages through livestock grazing, under an agri-environmental agreement with Natural England. Since 1969, Cumbria Wildlife Trust has employed a

seasonal warden to monitor the site's bird populations, helping to develop a picture of the site's ecological condition.

Rockcliffe Marsh lies within the Upper Solway Flats and Marshes, which is a RAMSAR site (a wetland of international importance), SAC, SPA and SSSI due to its wintering wildfowl and waders, summer breeding birds and internationally important transitional estuarine vegetation. Substantial accretion has occurred along the western and southern edges of the marsh, whilst significant erosion has been documented along the northern edge. For many years, accretion has outweighed erosion, leading to the formation of new areas of pioneer and lower salt-marsh communities. The extent of accretion appears to have decreased in recent years, according to the 2019 Warden's Report (Burge, 2021). Accretion occurs along the banks of the River Esk and Eden that run through the site, carrying in supplies of sediment.

During spring and summer, the site is grazed by cows and sheep. The site is considered to be heavily grazed but the levels of grazing are in line with the agri-environmental agreement and the requirement to maintain the designated site's interest features. Over winter, the grazing pressure is maintained, as thousands of overwintering geese use the site to forage. The saltmarsh at Rockcliffe is not representative of a natural ecosystem because of the thousands of years of agriculture on the site.

Like many of the saltmarshes along the North West coast of England, many of the creeks at Rockcliffe were drained to increase the area suitable for grazing or to facilitate turf cutting. This has reduced the saltmarsh's natural mosaic with fewer wet areas and associated invertebrates.

In around 2018, with the support of Natural England, Rockcliffe Marsh was put into a Higher-Level Stewardship scheme/Countryside Stewardship Scheme. The aim was to reverse the drainage and restore wet areas or 'flash features', creating a more diverse habitat suitable for both geese (i.e. low cropped swards) and for breeding waders (i.e. rougher vegetation) as well as encouraging a mosaic of wet ground, creeks and open water amongst the vegetation. Artificial drains were blocked using saltmarsh sediment to create small dams, this allowed pools of standing water to remain when the tide retreats. Wet flashes have also been dug alongside artificial drains that need to be retained to allow water to pass from the land to the sea. Flashes create areas that can become flooded seasonally, to create habitat for waders and invertebrates. Since making these changes the seasonal wardens have recorded a higher number of wildfowl and ducks. The flashes were also observed being used by breeding waders, passage birds and wintering waterfowl within just a couple of weeks.

Campfield Marsh – RSPB

Campfield Marsh is an RSPB reserve that contains a small strip of saltmarsh covering 52ha, it is situated between Bowness-on-Solway and Cardunock. Similar to many other saltmarshes on the Solway, the site had been artificially drained for agriculture. The RSPB, with support from Natural England, have carried out 're-wetting' work, by blocking artificial drains, to restore the saltmarsh to a more natural state. The saltmarsh here is characterised by prominent steps (marsh terraces) that divide the marsh into zones, between the steps are natural basins that have been flooded and now provide a habitat with wet features and islands for breeding birds. Within the first year, the newly created islands attracted two to six pairs of breeding redshank and have been used throughout the year by both waders and wildfowl. The new islands also provide habitat for terns and avocet.

Potential to replicate enhancement at other sites

Other areas of saltmarsh on the Solway have also been historically drained for agricultural improvement. As the Solway is underdeveloped compared to other estuaries in the UK, there is huge potential to naturalise the saltmarshes by rewetting and creating natural habitat variation. Re-wetting saltmarshes by blocking artificial drains is a relatively easy method of saltmarsh restoration. However, there may need to be incentives for farmers and landowners to do so. The Countryside Stewardship Scheme may make re-wetting activities feasible for landowners as it provides financial incentives for managing the saltmarsh, as an alternative to income from grazing alone. There is a desire from some landowners to carry out such work (pers. comms Blackledge, D). Some landowners have expressed an interest in replicating the success of the enhancement at Campfield Marsh. Similar enhancement work may be feasible on adjacent marshes as these have similar features. Farms within the Solway Coast AONB can apply for funding through the Farming in Protected Landscapes scheme. This funding supports farmers and land owners to carry out projects which benefit nature recovery, mitigate climate change, provide opportunities for people to connect with the landscape and its cultural heritage and protect or improve the quality and character of the landscape or place.

6.1.5.3 Management of grazing

As discussed above, grazing levels are high at most of the marshes on the Solway. Saltmarsh grazing is an important income for many local farmers through selling the livestock's meat that can be marketed as having a unique flavour, like 'saltmarsh lamb'. However, during consultations, stakeholders expressed that the saltmarshes are overgrazed and that one of the most important first steps to improve the saltmarshes will be to reduce grazing levels.

Marshes that have not been historically heavily grazed usually have greater diversity than those that have. These sites are uncommon in the UK where most marshes have experienced some grazing pressure for many years. However, the removal of grazing on formerly grazed marsh does not necessarily lead to a rich or diverse marsh community that would have been seen prior to grazing. Instead, removal of grazing leads to communities dominated by a few species, maintaining a low diversity system. Light grazing by native herbivores (e.g. ducks and geese, as well as and low levels of seasonal grazing by livestock), replicates the most 'natural un-grazed' system. It typically allows for good variation in the structure and diversity of plants and invertebrates.

An ideal grazing regime would compromise of a range of grazing pressures across the site to provide diversity in sward height. This would allow a mix of different species adapted to specific conditions to coexist. In practice, this balance is difficult to achieve at most sites due to conflicting management requirements.

Rotation of grazing across the marsh throughout the year generates local disturbance, allowing plants with high growth rates and low growth forms to develop. After grazing moves on to a new area, or ends for the season, other plant species with higher swards can grow and the marsh has the opportunity to regenerate. At Campfield Marsh, the RSPB are trialling 'no fence' collars, which should allow for the rotation of livestock across the marsh. This could make grazing management more adaptable as the cattle can move between areas over the season and grazing can be excluded in areas where constructing fences is more challenging. If successful, this could be replicated across more of the Solway's marshes.

Having a greater diversity of vegetation structure and composition will not only improve the biodiversity value of the saltmarshes, but it may improve their flood defence function. Where

the marsh has a greater surface roughness, its ability to provide flood defence benefits is improved due to slowing the flow of water (Adnitt et al., 2007).

Changing grazing management may be challenging because they are managed by a 'marsh committee'. The Solway's marshes are common land, divided into 'stints'. A marsh committee auctions off stints, allocating each grazier an area of land on which they can graze a set number of sheep and cattle. The marsh committee can come in the way of saltmarsh restoration/enhancement work if not everyone on the committee is interested in reducing grazing. It is, therefore, crucial to get everyone on-board if there are to be any change to grazing regimes. Getting stint owners to reduce cattle will also depend on how the Countryside Stewardship Scheme (CSS) is incentivising the work.

Currently, a landowner can earn £90 per hectare for the Management of Coastal Saltmarsh, in-line with the requirements set out in the Countryside Stewardship scheme. The Countryside Stewardship scheme may also provide an opportunity to block drains and add pools, however, if farmers prefer to have high levels of grazing, as this is most financially reliable/profitable, then it is unlikely there will be any change in the grazing regime unless the Countryside Stewardship offsets the cost of reducing grazing stocks. However, currently farmers can get supplements for removing sheep and using cattle instead and following a grazing regime.

Recommendation

Hold discussions with stakeholders about making changes to grazing levels.

6.1.6 Key findings

- The Solway's marshes are extensive and nationally important, they are well protected within multiple designated sites which means there is relatively good information available on their condition.
- Saltmarshes contribute to the following beneficial ecosystem services: they play a key role in mitigating the impacts of climate change through carbon sequestration and storage; they stabilise sediment reducing the risk of coastal erosion; they reduce the risks from flooding by dissipating wave and tidal energy; they maintain nursery populations and habitats for important fish and shellfish species including European smelt; they provide cultural services, including tourism and recreation and health and wellbeing; and they help to regulate coastal water quality.
- The saltmarsh is not in a state of erosion and overall, they have been expanding in recent years but their extent should continue to be monitored.
- Saltmarshes are heavily grazed to levels suitable for the wildfowl species that are important to the area. However, there is a general view from stakeholders that many of the marshes are overgrazed and reducing grazing levels may enhance the saltmarsh's diversity.
- The impacts of climate change, particularly sea level rise, is a key threat to the Solway's saltmarshes. Agricultural management including grazing regimes and nutrient run off were also identified as key pressures.
- From conversations with stakeholders, there are limited opportunities for habitat creation or landward expansion because of the natural topography of the coast and the relatively low levels of land reclamation.

- Further conversations between stakeholders should be held to discuss opportunities for saltmarsh expansion or enhancement in sites identified by the Countryside Stewardship scheme.
- It will be most important and feasible to enhance the marshes that already exist through re-wetting and reducing grazing levels.

Saltmarsh Logic Chain

Figure 13 Natural capital logic chain for saltmarsh

Recommendation

Logic chains should be completed for the Solway's other important marine and coastal natural capital assets, including sand dunes and biogenic reefs

6.2 Sand dunes

Although logic chains for sand dunes were not completed during this project, the following information provides a brief overview of the asset in the Solway.

A 17km narrow strip of sand dune and dune heath can be found along the coast of the Solway from Grune Point down to Allonby Bay. The largest stretch covers 8km between Dubmill Point and Silloth, but there are also two smaller areas between Maryport and Allonby and Skinburness and Grune Point (Figure 14). The Solway Coast AONB encompasses 260ha of sand dune, 242ha have been identified as priority habitat by Natural England.

Sand Dune Location

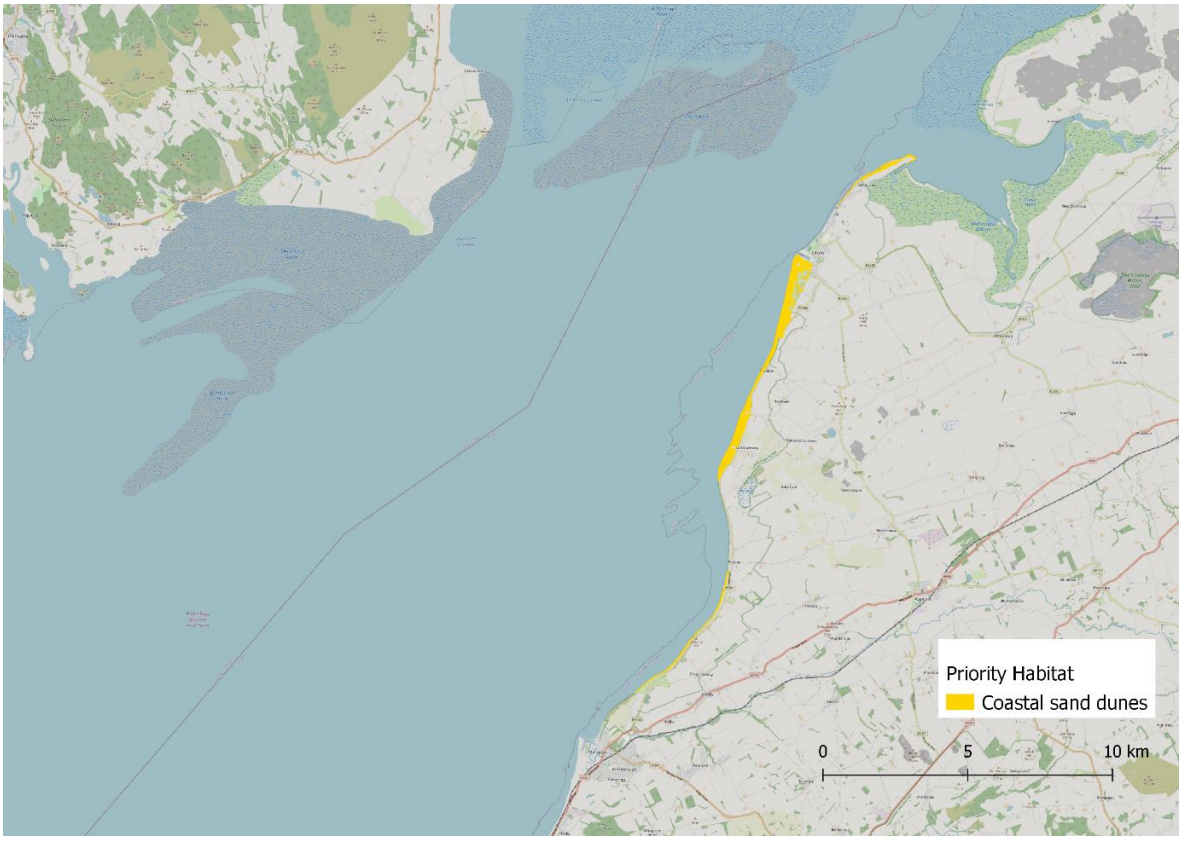

Figure 14 Sand dune locations on the English Solway. Data is from Natural England's Priority Habitats Inventory dataset. © OpenStreetMap contributors. Data is available under the Open Database License

The area of sand dune between Grune Point and Dubmill Point is within the Solway Firth SAC and the fixed dunes (Annex 1 Habitat) are a qualifying interest feature. This stretch of dune is also an interest feature in the Upper Solway Flats and Marshes SSSI. Silloth Dunes and Mawbray Bank SSSI covers the 8km of dune from Dubmill Point to Silloth. This site represents one of just three sand dune systems in West Cumbria. It is particularly important because of its transition from vegetated shingle bank to mobile and fixed sand dune communities to grassland and maritime heath. It is also an important breeding site for natterjack toad and great crested newt.

Sand dunes provide several ecosystem services including coastal protection, cultural services and improved water quality. Their greatest contribution however, is to habitat creation.

Sand dunes are a rare and declining habitat and listed as the most at-risk habitat in Europe. On the Solway coast, sand dunes have been modified for grazing and recreational activities such as golf courses, as well as the creation of car parks (Solway Coast AONB, 2022). Other key pressures include:

1. Over stabilisation caused by a lack of grazing and increased nitrogen deposition which has led to overgrowth of scrub vegetation.
2. Invasive species (Japanese rose, ~~(~~*Rosa rugosa*)
3. Trampling and damage
4. Coastal squeeze
5. The Cumbria Coastal Strategy identifies coastal erosion of the beach, dunes and backshore as the key risk between Dubmill and Grune Point (Cumbria County Council, 2020).

On the Solway coast, at Mawbray Banks and Grune Point, sand dune restoration is being carried out as part of the Dynamic Dunescapes project. The work is being led by Natural England working in partnership with Cumbria Wildlife Trust and the Solway Coast AONB. At these sites, the sand dune systems are threatened by overstabilisation and the invasive species Japanese rose (*Rosa rugosa)*.

At Mawbray Banks, there have been efforts to remove invasive species and scrub species such as gorse. Cattle have also been introduced to graze the vegetation to help return the dunes to a more natural dynamic state. Cattle are being trained for no-fence grazing at this site and will be moved further North to help improve the dune quality at other sites. Grazing and scrub removal will help to create more exposed areas of bare sand. Areas of bare sand are an essential component of sand dune systems. They provide an important habitat for invertebrate species and enable small scale erosion and recolonisation by pioneer species; improving overall diversity within the system. They also allow wet areas to form which are used as breeding sites for natterjack toad.

At Grune Point, grazing has also been introduced. However, the removal of Japanese rose has not taken place as the landowners believe this would make the dunes more vulnerable to erosion, instead there has been an effort to remove gorse from the back edge of the dunes. Wet areas have also been restored, increasing breeding ponds for the natterjack toads.

There is great potential and a desire to see this work continued at other sites in North Cumbria. The priority for future sand dune restoration will be removal of invasive species and the introduction of grazing. Japanese rose is present elsewhere along the Solway and there should be an effort to remove it where possible. Once these activities have begun, the creation of pools and turf stripping can be considered. Dunes between Mawbray Banks and the Silloth Golf course would benefit from similar improvement work (pers. comms Storton, R). Considering the shortlisted sites for Dynamic Dunescapes could help to find sites to focus future restoration work.

The sand dunes of the Solway are managed by private landowners, therefore early consultation and engagement will be vital for the success of any future work. As the dunes are within designated sites, they must be managed to maintain favourable condition. This should incentivise landowners to allow restoration projects to be undertaken on them.

Dynamic Dunescapes has demonstrated a successful community engagement and citizen science programme. Involving people in restoration work and encouraging responsible use of the dunes will help people to recognise their value and realise their cultural values.

A Sand Dune Managers Handbook has been created as part of the Dynamic Dunescapes. Project. It provides in-depth information on a range of dune management options to address the conservation needs of this important natural capital asset (Jones et al., 2021).

6.3 Intertidal biogenic reefs

In the Solway, intertidal biogenic reefs are formed by blue musses (*Mytilus edulis*) and honeycomb worms (*Sabellaria alveolata*). Some of the most extensive biogenic reefs in the UK can be found in the Solway estuary particularly at Dubmill Point.

Intertidal biogenic reefs are important natural capital assets, they provide the following beneficial ecosystem processes: primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification, erosion control, biogeochemical cycling, and water purification. These processes support the following ecosystem services that are beneficial to humans: fisheries, aquaculture, fertiliser/feed, natural hazard protection and environmental resilience (i.e. biogenic reefs stabilise sediment reducing erosion from wave energy).

Honeycomb worm reefs - Sabellaria alveolata

Honeycomb worms are polychaete worms that use tiny particles of sand and shell to create colonies of tubes, that form biogenic reefs. Honeycomb worm reefs are valuable natural capital assets. They increase an area's habitat complexity providing microhabitats for a diverse community of species from sponges and soft corals, and dahlia anemones to spider crabs. As well as habitat formation and species diversification, honeycomb worm reefs play an important role in food web dynamics, they are a primary consumer of phytoplankton, filtering vast volumes of water each day. Their function as biological filters is also important for processing and cycling organic matter and nutrients as well as purifying water. The reefs also provide coastal protection by reducing wave energy and stabilising sediments (Fletcher et al., 2012).

The Solway coast has some of the UK's most extensive areas of honeycomb worm reef. It is present all along the coast of the outer Solway (Figure 15). The most significant areas are a Feature of Conservation Importance within Allonby MCZ. The densest area of honeycomb worm reef can be found at Dubmill Point, covering more than 3km^2, the reef then continues in a band along the lower shoreline of Allonby Bay for almost 9km.

Honeycomb Worm Location

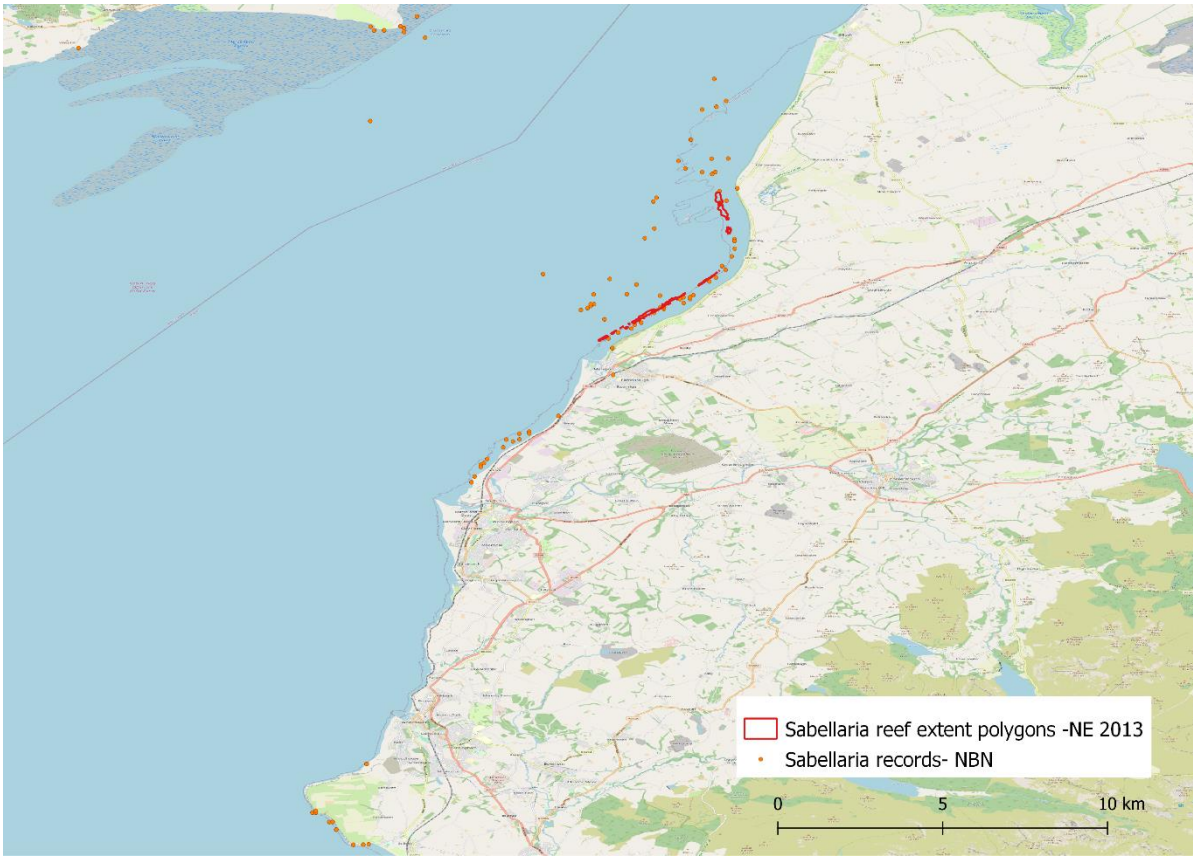

Figure 15 Point data of Sabellaria alveolata records from the NBN Atlas and polygons from surveys of Allonby Bay conducted by Natural England and Cumbria Wildlife Trust, 2013. © OpenStreetMap contributors. Data is available under the Open Database License

There are no examples of *Sabellaria alveolata* reef restoration in the UK. The species are able to colonise artificial structures suggesting that there may be potential to create new reefs by providing suitable settlement substratum near to existing reefs. The success of this will depend on the environmental conditions, including hydrodynamics and whether there is suitable food supply (MMO, 2019). Further research needs to be done before this can be recommended as a feasible option for restoration.

Cumbria Wildlife Trust and Natural England are continuing to investigate how remote monitoring technologies (such as UAVs) can be used to improve regular monitoring of the extent of intertidal reef habitats (e.g. *Sabellaria alveolata*) within Allonby Bay MCZ.

Recommendation

Research potential methods for *Sabellaria* restoration or enhancement

Blue mussels - *Mytilus edulis*

Blue mussel beds can be found within Allonby Bay MCZ in both the intertidal and subtidal areas. Blue mussels are an important part of marine ecosystems, playing a role in coastal sediment dynamics, providing a food source for over-wintering wader and enhancing biodiversity by creating complex habitat in an otherwise sediment dominated environment. The location of blue mussels on the Solway coast can be seen in Figure 16. Polygons showing the location and extent of blue mussel beds can be viewed on Defra's Magic Maps or EMODnet Seabed Habitats data portal.

Blue Mussels Location

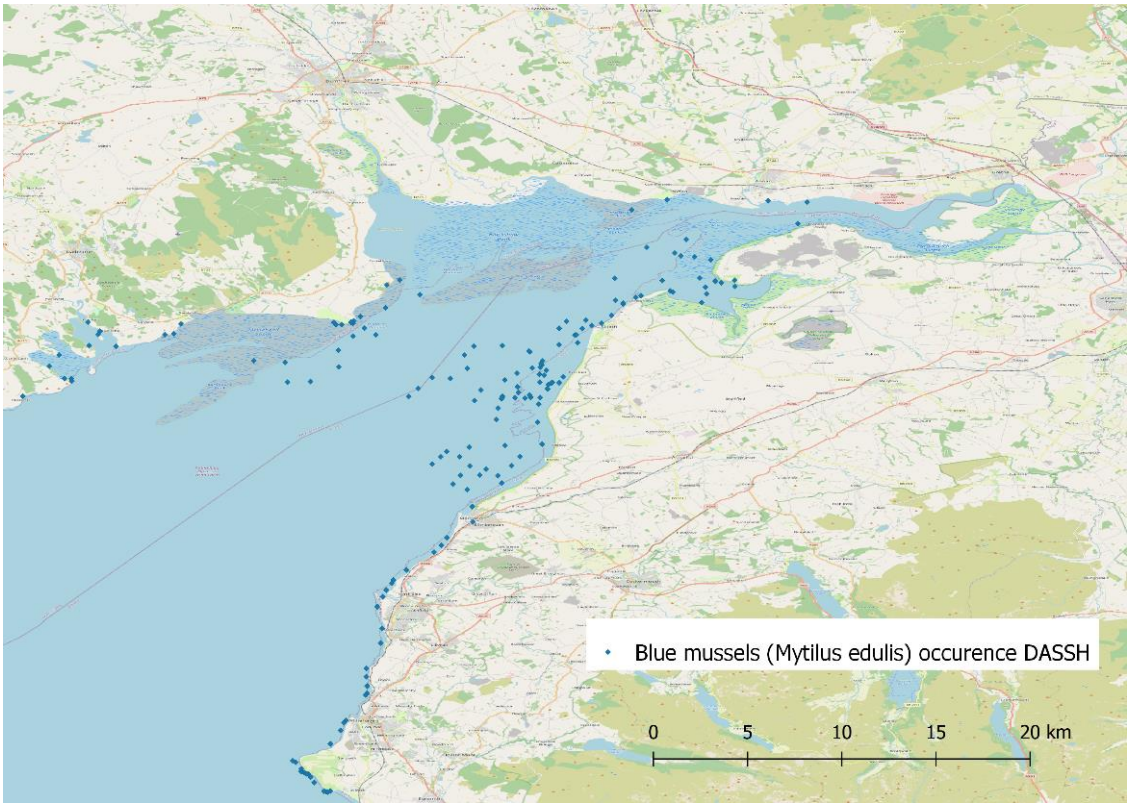

Figure 16 Point data showing the occurrence of blue mussels in the Solway. Data is from DASSH database. © OpenStreetMap contributors. Data is available under the Open Database License

The NW-IFCA have developed a methodology to overcome the difficulties of surveying mussel beds in the area where it is shallow, has significant tidal flow, and a high sediment load. The methodology includes using side-scan sonar, ground-truthed with a Hamon grab. This surveying will allow the NW-IFCA to build up evidence of the changes in the presence, extent and formation of the mussel beds. The most recent survey indicates that large areas, with a range of sediment types, have the potential to be covered in blue mussels (NWIFCA, 2021).
More data should become available on the condition of biogenic reefs within Allonby Bay MCZ following the first condition assessment which is currently in process.

7 Conclusions

This project has produced an overview of the marine and coastal natural capital assets in the Cumbrian Solway Firth using the best available data. The marine area is dominated by sublittoral sediments, particularly circalittoral sandy mud and deep circalittoral sand. Extensive and important biogenic reefs formed by blue mussels and honeycomb worms are also present.

The coast is dominated by grazed saltmarsh, and narrow strips of important sand dune habitat. These assets provide valuable benefits from climate change mitigation to alleviating flood and erosion risk. They also form habitats, increasing biodiversity and maintaining nursery populations of important fish and shellfish species. They play a role in regulating water quality and provide several cultural services.

Stakeholders agreed that more data is needed before deciding on priority assets and sites to restore or enhance. However, from what we know already, saltmarshes, sand dunes and water quality are of particular importance to the Cumbrian Solway.

There is a relatively good amount of information on the state of saltmarshes and sand dunes because their condition is monitored as part of the protected area condition assessments carried out by Natural England. This enabled a relatively detailed assessment of the state of saltmarshes to be completed following Natural England's natural capital logic chain as a template. The short timescale of this project meant the same could not be done for sand dunes but there is likely enough data available to do this. There is less data available on the state of marine habitats, such as biogenic reefs. This should improve following the completion of the MCZ condition assessments which are currently in progress.

Saltmarshes are generally in good condition showing an increase in extent and clear zonation. However, they have been historically modified for agriculture and experience heavy levels of grazing. This may impact their ability to provide ecosystem services but more research needs to be done in this area. There is great potential to naturalise the marshes replicating the successful restoration at Rockcliffe and Campfield marshes. There may also be potential to enhance and expand the marshes along the coast in areas highlighted for managed realignment by the Cumbria Coastal Strategy. The suitability of these sites needs to be explored in more detail and there needs to be more evidence that this will increase the provision of beneficial ecosystem services.

8 Next steps

A number of recommendations for future work have been made through the project, these are listed throughout the report in relevant sections and have been collated in the executive summary.

This project provides the ground work for future marine and coastal natural capital work. Building on this and producing a full baseline assessment of all the marine and coastal natural capital assets in the Cumbrian Solway Firth will be an important first step. More data and monitoring may need to be completed for the state of the natural capital assets to be assessed and to better understand what quality indicators are impacting the value and long-term provision of ecosystem benefits. The sites suggested for managed realignment should be explored in depth to see if they are suitable and whether the changes will positively impact the provision and value of ecosystem services. The potential for improving the quality

of existing saltmarshes through re-wetting and reducing grazing levels should also be considered further.

9 References

Adnitt, C., Brew, D., Cottle, R., Hardwick, M., John, S., Leggett, D., McNulty, S., Meakins, N. and Staniland, R. 2007. Saltmarsh Management Manual. R&D Technical Report SC030220. Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme. Environment Agency. ISBN: 978-1-84432-714-0. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290974/scho0307bmkh-e-e.pdf [Accessed 20/30/22]

Armstrong, S., Burns, O., Garbutt, A., Hudson, R., Rendón, O., Thomas, M., Roberts, E., Preston, J. 2021. Chapter 2 Getting Started. In: Saltmarsh Restoration Handbook: UK and Ireland (eds. R. Hudson, J. Kenworthy and M. Best), pp.1-16. Environment Agency, Bristol, UK.

Aspden, R., Vardy, S., and Paterson, D. 2004. Salt Marsh Microbial Ecology: Microbes, Benthic Mats and Sediment Movement. In: Fagherazzi, S. Marami, M. Blum, L. (eds). The Eco-geomorphology of Tidal Marshes, American Geophysical Union.

Barbier, E., Hacker, S., Kennedy, C., Koch, E., Stier, A. and Silliman, B. 2011. The value of estuarine and coastal ecosystem services. Ecological Monographs, 81, pp.169-193. https://doi.org/10.1890/10-1510.1

Beaumont, N., Jones, L. Garbutt, A., Hansom, J. and Toberman, M. 2014. The value of carbon sequestration and storage in coastal habitats. Estuarine, Coastal and Shelf Science, 137, pp.32-40.

BEIS. 2019. Valuation of energy use and greenhouse gas. Supplementary guidance to the HM Treasury Green Book on appraisal and evaluation in central government.

Burge, J. 2021. Rockcliffe Marsh Seasonal Warden's Report 2021. Cumbria Wildlife Trust.
Cattrijsse, A., Dankwa, H. R., Mees, J. 1997. Nursery function of an estuarine tidal marsh for the brown shrimp *Crangon crangon*, Journal of Sea Research, 38(1–2), pp. 109-121, https://doi.org/10.1016/S1385-1101(97)00036-1

Climate Central Inc., 2021. Sea level rise and coastal flood risk maps - a global screening tool by Climate Central. [online] Coastal.climatecentral.org. Available at: https://coastal.climatecentral.org/map/9/-3.4698/54.8515/?theme=sea_level_rise&map_type=year&basemap=roadmap&contiguous=true&elevation_model=best_available&forecast_year=2100&pathway=ssp3rcp70&percentile=p50&refresh=true&return_level=return_level_1&rl_model=gtsr&slr_model=ipcc_2021_med [Accessed 25/03/22].

Colclough, S., Coates, S., Dutton, C., Cousins, T. and Astley, T. 2003. *The potential for fisheries enhancement associated with managed realignment*. Wetland valuation: state of the art and opportunities for further development. Proceedings of a Workshop. [online] London: Environment Agency, pp.41-49. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.474.7988&rep=rep1&type=pdf#page=44 [Accessed 22/03/22].

Colclough, S., Fonseca, L., Astley, T., Thomas, K. and Watts, W., 2005. Fish utilisation of managed realignments. *Fisheries Management and Ecology*, 12(6), pp.351-360.

Cumbria County Council, 2020. Cumbria Coastal Strategy. Jacobs Consultancy Ltd. Available at https://www.cumbria.gov.uk/ccs/reports.asp [ccessed 20/03/22]

Defra and Environment Agency, 2021. England | Catchment Data Explorer. [online] Environment.data.gov.uk. Available at: https://environment.data.gov.uk/catchment-planning/v/c3-draft-plan [Accessed 18/03/22].

EKOS Limited and Solway Firth Partnership, 2020 *Socio-Economic Analysis of the English Solway*. [online] Available at: https://www.solwayfirthpartnership.co.uk/wp-content/uploads/2020/04/SEAES-Report-March-2020.pdf [Accessed 24/03/22].

Ellis, J., Milligan, S., Readdy, L., Taylor, N. and Brown, M. 2012. Spawning and nursery grounds of selected fish species in UK waters. Sci. Ser. Tech. Rep., Cefas Lowestoft, 147, pp.56

Environment Agency. 2017. Working with Natural Processes to Reduce Flood Risk. The evidence base for working with natural processes to reduce flood risk. Available at: https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/working-with-natural-processes-to-reduce-flood-risk#reports [Accessed 28/03/22]

Environment Agency. 2022. National Coastal Erosion Risk Mapping (NCERM) - National (2018 - 2021). Available at: https://data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021 [Accessed: 11/03/22]

Fletcher, S., Saunders, J., Herbert, R., Roberts, C. and Dawson, K. 2012. Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area. Natural England Commissioned Reports, Number 088. Available at: http://publications.nturalengland.org.uk/publication/301112 [Accessed 28/03/22]

Green, A., Unsworth, R., Chadwick, M and Jones, P. 2021. Historical Analysis Exposes Catastrophic Seagrass Loss for the United Kingdom. Front. Plant Sci. 12:629962. DOI: 10.3389/fpls.2021.629962

Gregg, R., Elias, J., Alonso, I., Crosher I., Muto P and Morecroft M. 2021. Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York. Available at: http://publications.naturalengland.org.uk/publication/5419124441481216 [Accessed 15/03/22]

Hawker, D., 1993. Eelgrass (Zostera) In The Solway Firth. Scottish Natural Heritage.

Haynes, T. 2016. Scottish saltmarsh survey national report. Scottish Natural Heritage Commissioned Report No. 786. Available at: https://www.nature.scot/sites/default/files/2017-05/Publication%202016%20-%20SNH%20Commissioned%20Report%20786%20-%20Scottish%20saltmarsh%20survey%20national%20report%20%28A2215730%29.pdf [Accessed 05/04/22]

Hily, C., van Katwijk, M., den Hartog, C. 2003. The Seagrasses of Western Europe. pp38-47. https://archive.org/details/worldatlasofseag03gree

Hooper, T., Ashley, M., Börger, T., Langmead, O., Marcone, O., Rees, S., Rendon, O., Beaumont, N., Attrill, M. and Austen, M. (2019a). Application of the natural capital approach to the marine environment to aid decision-making. Phase 1 Final Report. Report prepared for the Department for Environment Food and Rural Affairs (project code ME5115). Available at: http://randd.defra.gov.uk/Document.aspx?Document=14440_FinalreportPhase1.pdf [Accessed 04/04/22]

Hudson, R., Kenworthy, J. and Best, M. (eds). 2021. Saltmarsh Restoration Handbook: UK and Ireland. Environment Agency, Bristol, UK. Available at: https://catchmentbasedapproach.org/wp-content/uploads/2021/10/Saltmarsh_Restoration_Handbook_FINAL_20210311.pdf [Accessed 28/03/22]

JNCC. 2004. Common Standards Monitoring Guidance for Saltmarsh Habitats. Available at: https://data.jncc.gov.uk/data/7607ac0b-f3d9-4660-9dda-0e538334ed86/CSM-SaltmarshHabitats-2004.pdf [Accessed: 09/03/22].

King, S. and Lester, J. 1995. The value of salt marsh as a sea defence. Marine Pollution Bulletin 30 pp.180– 189.

Laffoley, D.d'A. and Grimsditch, G. (eds). 2009. The management of natural coastal carbon sinks. IUCN, Gland, Switzerland. 53 pp. Available at: https://www.iucn.org/lo/content/management-natural-coastal-carbon-sinks-2 [Accessed 28/03/22]

Lear, R., Wigley, S., Lord, A., Lusardi, J., and Rice, P. 2021. Natural Capital Atlases: Mapping Indicators for County and City Regions, Natural England Commissioned Report Number 318. Second edition. Natural England. Available at: http://publications.naturalengland.org.uk/publication/6672365834731520 [Accessed 28/03/22]

Lusardi, J., Rice, P. Waters, R. and Craven J. 2018. Natural Capital Indicators: for defining and measuring change in natural capital. Natural England Research Report, Number 076. Available at: http://publications.naturalengland.org.uk/publication/6742480364240896 [Accessed 28/03/22]

Lush, M., Haynes, T., and Lush, C. 2016. *Spartina anglica* and its management in estuarine Natura 2000 sites: an update of its status and monitoring future change in England (IPENS041). Natural England. Available at: http://publications.naturalengland.org.uk/publication/5109184527859712?category=6337991412809728 [Accessed: 09/03/22].

Marine Management Organisation, 2021. UK Sea Fisheries 2020. [online] ArcGIS StoryMaps. Available at: https://storymaps.arcgis.com/stories/012e529682ef43ebb1e9a5caf94a0b27 [Accessed 24/03/22].

Marine Management Organisation, 2021. UK Sea Fisheries 2020. [online] ArcGIS StoryMaps. Available at: https://storymaps.arcgis.com/stories/012e529682ef43ebb1e9a5caf94a0b27 [Accessed 24 March 2022].

Mcleod, E., Chmura, G., Bouillon, S., Salm, R., Bjork, M., Duarte, C., Lovelock, C., Schlesinger, W., Silliman, B. 2011. A blueprint for blue carbon: towards an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment, 9(10), pp.552-560.

Miles. R and Richardson. N. 2018. Sustainable Shores (Technical Report). Royal Society for the Protection of Birds (2018). Available at: https://www.rspb.org.uk/globalassets/downloads/projects/sustainable-shores-project---technical-report.pdf [Accessed: 11/03/22]

MMO. 2019. Identifying sites suitable for marine habitat restoration or creation. A report produced for the Marine Management Organisation by ABPmer and AER, MMO Project No: 1135, February 2019, 93pp. Available at: https://www.gov.uk/government/publications/identifying-sites-suitable-for-marine-habitat-restoration-or-creation-mmo1135 [Accessed 28/03/22]

Möller, I., Spencer, T., Best, M., Austin, W. and Burden, A., 2021. Chapter 1 Saltmarsh Restoration: An introduction. In: Saltmarsh Restoration Handbook: UK and Ireland (eds. R. Hudson, J. Kenworthy and M. Best), pp.1-16. Environment Agency, Bristol, UK.

Mossman, H., Pontee, N., Born, K Lawrence, P., Rae, S., Scott, J., Serato, B., Sparkes, R., Sullivan, M., Dunk, R. 2021. Rapid carbon accumulation at a saltmarsh restored by managed realignment far exceeds carbon emitted in site construction. 10.1101/2021.10.12.464124.

Natural England and RSPB. 2014 Climate Change Adaptation Manual. Chapter 27. Coastal saltmarsh. Available at: http://publications.naturalengland.org.uk/publication/5629923804839936 [Accessed 22/03/22]

Natural England and Scottish Natural Heritage, 2010. Solway European Marine Site, Natural England and Scottish Natural Heritage advice given in compliance with Regulation 33 (2) and in support of the implementation of The Conservation (Natural Habitats &c.) Regulations 1994 (as amended) Interim Revision 2010. Available at http://publications.naturalengland.org.uk/publication/3189597?category=3212324 [Accessed: 11/03/22].

Natural England, 2014. *NCA* Profile: 07 West Cumbria Coastal Plain (NE568). [online] Available at: http://publications.naturalengland.org.uk/publication/6207059431260160?category=587130 [Accessed 24/03/22].

Natural England, 2014. NCA Profile: 07 West Cumbria Coastal Plain (NE568). [online] Available at: http://publications.naturalengland.org.uk/publication/6207059431260160?category=587130 [Accessed 24/03/22].

Natural England, 2015. NCA Profile: 06 Solway Basin NE536. [online] Available at: http://publications.naturalengland.org.uk/publication/5276440824119296?category=587130 [Accessed 24/03/22].

Natural England, 2015. NCA Profile: 06 Solway Basin NE536. [online] Available at: http://publications.naturalengland.org.uk/publication/5276440824119296?category=587130 [Accessed 24/03/22].

Natural England. 2022. Condition of SSSI Units for Site Upper Solway Flats [online] Available at: https://designatedsites.naturalengland.org.uk/sitedetail.aspx?SiteCode=S1001196&SiteName=&countyCode=&responsiblePerson=&unitId=&SeaArea=&IFCAArea [Accessed 05/04/22]

NW-IFCA, 2021. Solway Subtidal Mussels Sonar Survey April 2021. [online] Available at: https://www.nw-ifca.gov.uk/app/uploads/Agenda-Item-9-Annex-A-Solway-Subtidal-Mussels-Survey-April-2021-Report.pdf [Accessed 24/03/22].

NW-IFCA, 2021. *Solway Subtidal Mussels Sonar Survey April 2021*. [online] Available at: https://www.nw-ifca.gov.uk/app/uploads/Agenda-Item-9-Annex-A-Solway-Subtidal-Mussels-Survey-April-2021-Report.pdf [Accessed 24/03/22].

Phillips, G., McGruer, K., Crook, D., Doria, L., Herbon, C., Khan, J., Mackie, T., Singleton, G. & Young, C. 2018. Condition of intertidal saltmarsh communities in coastal waters determined using Water Framework Directive methods. Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/benthic-habitats/intertidal-saltmarsh/ [Accessed: 09/03/22].

Pilcher, R., Burston, P., Kindleysides, D., David, R. 2002. Royal Society for the Protection of Birds, Seas of Change Report. Available at: https://ww2.rspb.org.uk/images/seasofchange_tcm9-132925.pdf [Accessed 11/03/22]

Potts, G. and Swaby, S., 1993. Review of the status of estuarine fishes. Peterborough: English Nature Research Reports, 34.

Scholle, J., Schuchardt, B., Schulze, S., Veckenstedt J. 2007. Situation of the smelt (Osmerus eperlanus) in the Ems estuary with regard to the aspects of spawning grounds and recruitment. BIOCONSULT publication for RWS – Rijksinstituut voor Kust en Zee (RWS-RIKZ),Sea Watch Foundation. 2022. [online] Available at: https://www.seawatchfoundation.org.uk/wp-content/uploads/2012/07/North-westEngland1.pdf [Accessed 24/03/22].

Simas, T. and Ferreira, J., 2007. Nutrient enrichment and the role of salt marshes in the Tagus estuary (Portugal). Estuarine, Coastal and Shelf Science, 75(3), pp.393-407.

Solway Coast AONB Partnership, 2020. The Solway Coast Area Of Outstanding Natural Beauty 2020-25 Management Plan. [online] Available at: https://www.solwaycoastaonb.org.uk/2019/wp-content/uploads/2020/09/Solway-Coast-AONB-Management-Plan-FINAL.pdf [Accessed 17/03/22].

Solway Firth Partnership. 2021. Marine Invasive Non-Native Species in the Solway Firth. Prepared by Solway Firth Partnership Feb 2021. Revised for 2021 – 2024. Available at: https://www.solwayfirthpartnership.co.uk/wp-content/uploads/2021/04/Marine-INNS-in-Solway-2021-2024.pdf [Accessed 24/03/22]

Solway Firth Partnership. 2022. Solway Review. [online] Available at: https://www.solwayfirthpartnership.co.uk/solway-review/ [Accessed 24/03/22].

Stafford, R., Ashley, M., Clavey, L., Estevens, L.S., Hicks, N., Jones, A., Leonard, P., Luisetti, T., Martin, A., Parker, R., Rees, S., Schratzberger, M., and Unsworth, R. 2021. Coastal and Marine Ecosystems. Nature-based Solutions for Climate Change in the UK: A Report by the British Ecological Society. London, UK., pp.107-190. Available at: https://www.britishecologicalsociety.org/policy/nature-based-solutions/read-the-report/

UNEP-WCMC, Short FT. 2021. Global distribution of seagrasses (version 7.1). Seventh update to the data layer used in Green and Short (2003). Cambridge (UK): UN Environment World Conservation Monitoring Centre. Data DOI: https://doi.org/10.34892/x6r3-d211

Wigley, S., Paling, N., Rice, P., Lord, A., and Lusardi, J. (2021) National Natural Capital Atlas, Natural England Commissioned Report Number 285. Second edition. Natural England. Available at: http://publications.naturalengland.org.uk/publication/4578000601612288 [Accessed 28/03/22]