Understanding how management of the Welsh MPA network can contribute to the protection and enhancement of blue carbon

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Cynhaliwyd adolygiad byr yn seiliedig ar dystiolaeth o'r llwybrau polisi a rheoleiddio i reoli carbon glas mewn ACAau yng Nghymru. Roedd hyn yn cynnwys adolygiad o'r posibilrwydd o gynnwys carbon glas yn Rheoliad 37 Amcanion Cadwraeth ACAau a'r fframwaith rheoleiddio sy'n cefnogi datblygiadau morol. O fewn yr amcanion cadwraeth, ystyrid y gellid cynnwys mwy o bwyslais ar bwysigrwydd cynefinoedd carbon glas ym mhob nodwedd. Yna, mae gan hyn y potensial o fwydo i mewn i'r cyngor ar gyfer gweithrediadau i amlygu'r rhai a allai achosi dirywiad neu aflonyddu ar gynefinoedd carbon glas. Mae fframweithiau rheoleiddio sy'n cefnogi datblygiadau morol yn aml yn cydnabod pwysigrwydd lliniaru newid hinsawdd. Gallai'r fframweithiau hyn fanylu ymhellach ar y potensial i ddefnyddio carbon glas fel dull o liniaru yn erbyn newid hinsawdd, a dylid lleihau'r difrod hwnnw i ostwng y potensial ar gyfer allyriadau carbon glas. Awgrymir hefyd defnyddio mesurau ehangach, megis dynodi AGAau a datblygu cynlluniau'n benodol ar gyfer diogelu ac adfer cynefinoedd carbon glas a chyfrif am garbon glas o fewn cyllidebau allyriadau carbon.

Executive summary

Blue carbon habitats such as mangroves, saltmarshes and seagrass meadows are globally recognised to support some of the highest rates of organic carbon burial. This recognition has led to the development of blue carbon strategies to mitigate climate change. There is a long-term trend of coastal habitat loss and degradation, and, where blue carbon stocks are unprotected from pressures or are in poor health, they have the potential to release stored carbon and ultimately contribute to carbon emissions. It is recognised that targeted management of blue carbon habitats has the potential to enhance the capacity of carbon sinks and further promote the storage of carbon dioxide in the marine environment.

Marine Protected Areas (MPAs) provide valuable protection for marine habitats and species through the management of human activity. MPAs cover the majority of Welsh national waters and encompass a wide range of blue carbon habitats. A large proportion of these habitats occur within the protected features of Special Areas of Conservation (SACs). The aim of this study was firstly to investigate the currently feasible management actions that will promote carbon storage and sequestration in Welsh SAC Annex 1 habitat features. Secondly, the implementation of possible management opportunities for blue carbon within existing legislation and policy frameworks was reviewed. The key objectives for this study were:

- To review potential management measures which promote carbon storage and sequestration in Welsh SAC Annex 1 habitat features using local regional and global examples.
- To relate potential management measures to Welsh SACs and evaluate the feasibility of each measure to each SAC and respective Annex 1 features: and
- To review the policy and regulatory pathways to managing blue carbon in Welsh SACs and how management of blue carbon can be implemented within the existing legislative and policy framework that governs SACs.

The literature review identified a wide range of measures covering the management of known pressures on blue carbon habitats, along with habitat restoration and habitat creation approaches. Protection of blue carbon habitats by managing known pressures, such as reduced water quality, access and recreation and fishing, was found to be the most common management tool if used with the potential to enhance blue carbon stocks. Habitat creation and restoration schemes have also been used for saltmarsh, seagrass and shellfish beds. The success of habitat creation and restoration projects relies on careful planning (including assessments, consents and timing of project) and management of potential pressures.

A range of potential management options for each SAC have been identified along with a high-level evaluation of the feasibility of implementation and wider ecosystem benefits of each measure. The potential management options for blue carbon habitats within Welsh SACs were based on the assumption that improving the condition and extent of Annex I features by managing pressures has the potential to enhance carbon storage and sequestration. It was considered that more evidence is needed on the actual relationship between habitat condition and the carbon storage and sequestration potential of such habitats to ensure effective management. This could also help to justify the implementation of such measures. Similarly, investigations on carbon storage and sequestration before and after management measures would have to be undertaken.

A short evidence-based review of the policy and regulatory pathways to managing blue carbon in Welsh SACs was undertaken. This included a review of the potential inclusion of blue carbon within the Regulation 37 Conservation Objectives of SACs and the regulatory framework supporting marine developments. Within the conservation objectives, it was considered that more emphasis could be included on the importance of blue carbon habitats within each feature. This then has the potential to feed into the advice for operations to highlight those which may cause deterioration or disturbance to blue carbon habitats. Regulatory frameworks which support marine developments often acknowledge the importance of mitigating climate change. These frameworks could further detail the potential for blue carbon to be used as a tool to mitigate against climate change, and that damage should be minimised to reduce the potential for blue carbon emissions. Wider measures, such as designating MPAs and developing plans specifically for protecting and restoring blue carbon habitats and accounting for blue carbon within carbon emission budgets are also suggested.

1. Introduction

The release of carbon dioxide into the atmosphere due to anthropogenic activities is a primary driver of global climate change. In March 2021, the Welsh Government set out a legal commitment to achieve net zero emissions by 2050. As part of this commitment, the Net Zero Wales plan was developed which recognised the importance of protecting and increasing natural carbon storage within the terrestrial and marine environment (Welsh Government, 2021a). Furthermore, in November 2019, the Welsh Government published the Welsh National Marine Plan (WNMP), which contained a commitment to 'improve the understanding and enable action supporting climate change adaptation and mitigation'.

Blue carbon habitats sequester and store carbon in the marine environment and act as a crucial global carbon sink. The realization that vegetated coastal habitats such as mangroves, saltmarshes and seagrass meadows support some of the highest rates of organic carbon burial globally has led to the development of blue carbon strategies to mitigate climate change. However, there is a long-term trend of coastal habitat loss and degradation in the marine environment, and, where blue carbon stocks are unprotected from pressures or are in poor health, they have the potential to release stored carbon and ultimately contribute to carbon emissions. There is therefore a pressing need to manage the threats to blue carbon stocks and promote the restoration and recreation of these habitats.

Targeted management of blue carbon habitats has the potential to enhance the capacity of carbon sinks and further promote the storage of carbon dioxide in the marine environment (Burrows *et al*., 2017). Marine Protected Areas (MPAs) are a mechanism to manage human activity in coastal and offshore regions for conservation and provide valuable protection of marine habitats and species. In Wales, there are a total of 139 MPAs covering 69% of the Welsh inshore waters. These MPAs contain a range of key blue carbon habitats, including saltmarshes, seagrass meadows and kelp beds. It is estimated that at least 99 km^2 of blue carbon habitat in Wales is located within the MPA network (Stewart and Williams, 2019). Special Areas of Conservation (SACs) account for 10% of the total carbon storage and 47% of the total carbon sequestration within blue carbon sediments in Welsh waters (Armstrong *et al*., 2020; Robbins *et al*., 2022).

With the recent knowledge of the blue carbon potential in the Welsh MPA network, there is a need to investigate how blue carbon habitats can be better managed. In Wales, there are already a range of projects aimed at restoring and creating blue carbon habitats, for example the Seagrass Restoration Project, the Severn Vision Project, Project ReStore, and the Cwm Ivy Marsh Habitat Creation Project (Stewart and Williams, 2019).

The aim of this study was to investigate the currently feasible management actions that will promote carbon storage and sequestration in Welsh SAC Annex 1 habitat features, and the implementation of new management opportunities for blue carbon within the Welsh SAC network; working within the existing legislative and policy framework that governs SAC management. The key objectives for this study were:

- To review potential management measures which promote carbon storage and sequestration in Welsh SAC Annex 1 habitat features using local, regional and global examples;

- To relate potential management measures to Welsh SACs and evaluate the feasibility of each measure to each SAC and respective Annex 1 features; and
- To review the policy and regulatory pathways to managing blue carbon in Welsh SACs and how management of blue carbon can be implemented within the existing legislative and policy framework that governs SACs.

2. Methodology

2.1. Blue carbon management in Welsh SACs

2.1.1. Review of management measures

In order to identify different high-level management measures that have the potential to promote blue carbon within the Welsh SAC network, a literature review has been undertaken. The scope of the review was focussed on measures which could be used to protect and enhance blue carbon habitats using local, regional and global examples including both inside and outside of MPAs. The habitats included are listed below and are based upon habitats within Armstrong *et al*. (2020), which identified the key following blue carbon habitats in Welsh waters:

- Saltmarsh;
- Seagrass;
- Kelp;
- Maerl beds;
- Shellfish beds; and
- Sediment habitats.

To facilitate the literature review, an evidence database was produced, which is presented in an accompanying spreadsheet (see Appendix A). The details captured for this review included:

- Blue carbon habitats;
- Management measures protecting or enhancing the blue carbon habitat;
- Associated SAC feature(s) which include the blue carbon habitat;
- Wider ecosystem benefits;
- Existing case studies of management;
  - Location;
  - Level of success;
- Timescale to achieve benefit;
- Confidence in effectiveness;
- Factors influencing effectiveness; and
- Evidence gaps and constraints.

For each blue carbon habitat, potential management measures were identified which have the potential to protect and enhance blue carbon stocks and sequestration.

The management measures identified during the review have been separated into two categories: ‘management of potential pressures’ and ‘habitat restoration and enhancement schemes’. The potential pressures were based on the pressures and threats identified as part of the LIFE Natura 2000 Thematic Action Plans (Natural Resources Wales (NRW), 2015) which have the potential to impact carbon storage and sequestration. Whilst this is not an exhaustive list of pressures which may affect blue carbon habitats, the best available evidence and expert knowledge were used to identify the key risks likely to impact carbon stocks and sequestration.

Case studies documenting the location, application and effectiveness of the management measures were assessed, and an evaluation of the of the benefits and limitations of each measure was also undertaken where appropriate. In some cases, this involved highlighting where further research or evidence is needed.

As case studies specifically on the effectiveness of management of carbon storage and sequestration are limited in the literature, studies on managing blue carbon habitats in general were also reviewed. It was assumed that the protection or enhancement of the blue carbon habitats would serve to maintain or increase the value of the carbon stock or sequestration rates.

2.1.2. Potential Welsh SAC management measures

In order to review the potential management measures in the context of Welsh SACs, the current condition of Annex I features was obtained from the indicative feature condition assessment for European Marine Sites (NRW, 2018). In these assessments, the condition of SAC features was inferred from the best available evidence and expert knowledge. The known and potential pressures which have the potential to impact feature condition (including extent) in relation to the blue carbon habitats were then collated from a variety of sources, including NRW (2018), the literature (cited where appropriate), and expert knowledge. Potential management measures were then linked to Welsh SACs, based on these known pressures.

It was assumed that addressing the potential pressures associated with the condition of an Annex I feature would benefit the associated blue carbon habitat and hence lead to the protection of carbon stocks or enhancement of sequestration. The feasibility of the management measures was inferred at a high level, on the basis of the relative ease of implementation and their potential effectiveness. In addition, the wider ecosystem benefits of implementing each measure were identified. It is important to note, however, that the detailed impacts the management measures may have on the carbon stocks and sequestration within Welsh SACs is unknown. Similarly, the potential implications of the measures on Annex 1 features and wider environmental receptors would also need detailed consideration prior to implementation.

Under the Environment (Wales) Act 2016, NRW aims to pursue the sustainable management of natural resources and has developed a specific set of principles to maintain and enhance the resilience of ecosystems and the social, economic and environmental benefits (ecosystem services) they provide. Therefore, for each management measure, the Principles of Sustainable Management of Natural Resources (SMNR) were also determined (NRW, 2016a). The SMNR principles include:

- Adaptive management - manage adaptively by planning, monitoring, reviewing and where appropriate, changing action;
- Scale - consider the appropriate spatial scale for action;
- Collaboration and engagement - promote and engage in collaboration and cooperation;
- Public participation - make appropriate arrangements for public participation in decision-making;
- Evidence - take account of all relevant evidence, and gather evidence in respect of uncertainties;
- Multiple benefits - take account of the benefits and intrinsic value of natural resources and ecosystems;
- Long-term - take account of the short, medium and long term consequences of actions;
- Preventative action - take action to prevent significant damage to ecosystems; and
- Building resilience - take account of the resilience of ecosystems.

2.2. Blue carbon management in policy and regulatory pathways

A short evidence-based review of the policy and regulatory pathways to managing blue carbon in Welsh SACs was undertaken. This included a review of the potential inclusion of blue carbon within the conservation objectives of SACs, and the regulatory framework supporting marine developments. Alternative methods which could be used to protect blue carbon habitats were also identified.

3. Management measures for blue carbon habitats

This review presents possible management measures and opportunities for habitat restoration and enhancement schemes which have the potential to protect and enhance blue carbon stores in Wales. A summary of Welsh blue carbon habitats and the potential pressures for which management measures could be implemented are presented in **Table 1**. A summary of Welsh blue carbon habitats and potential habitat restoration and enhancement schemes are presented in **Table 2**.

Further detail and case studies of management are provided throughout Section 3. Overall, protection of habitats through the management of known pressures was found to be the most common management tool likely to enhance blue carbon stocks. In this context, several pressures have been identified as impacting the extent or condition of blue carbon habitats. In addition, key initiatives which aim to restore and create blue carbon habitats were also reviewed.

Table 1. Summary of blue carbon habitats and the potential pressures for which management could be implemented.

Blue carbon habitat	Water Quality	Grazing	Access and recreation	Fishing	Invasive non-native species	Pathogens and disease
Saltmarsh	Yes	Yes	Yes	No	Yes	No
Seagrass	Yes	No	Yes	Yes	Yes	Yes
Kelp	Yes	No	Yes	Yes	Yes	No
Maerl beds	Yes	No	Yes	Yes	Yes	No
Shellfish beds	Yes	No	No	Yes	Yes	Yes
Sediment habitats	Yes	No	Yes	Yes	No	No

Table 2. Summary of blue carbon habitats and associated habitat restoration and enhancement schemes.

Blue Carbon habitat	Sediment recharge	Habitat creation schemes	Replanting / reseeding / translocation
Saltmarsh	Yes	Yes	Yes
Seagrass	No	No	Yes
Kelp	No	No	Yes
Maerl beds	No	No	No
Shellfish beds	No	Yes	Yes
Sediment habitats	No	No	No

Crucial pressures identified as having potential impacts on blue carbon habitats were construction, development and mechanical harvesting (for example, harvesting of kelp). However, in order to obtain a marine licence (or equivalent permission) for projects which could affect Welsh SACs and associated feature condition, a Habitats Regulations Assessment (HRA) is required. This would include, for example, understanding the baseline environment (including surveys), detailed assessments and the provision of mitigation and compensation as appropriate. It was, therefore, assumed that regulatory measures were already in place to manage the pressures associated with these pressures and thus were not reviewed further in this report. It should be noted that HRA does not specifically require assessment of impacts on blue carbon, therefore this assumption is based on the link between feature condition and carbon sequestration potential

This review focussed on current management measures which could be implemented within Welsh SACs to protect and enhance blue carbon habitats. However, it is important to acknowledge that one of the largest threats to these blue carbon habitats is climate change. Management can be implemented with the aim to mitigate against some aspects of climate change. Sea level rise as a result of climate warming is predicted to lead to more coastal flooding with end-of-the-century projections estimating a rise of up to 1 m along the Welsh coastline (Oaten *et al*., 2021). Sea level rise was identified as one of the key pressures that could lead to loss of habitats such as saltmarshes, mudflats and sandflats in Wales (Oaten *et al*., 2021). Equally, changes to storm patterns (frequency and intensity) and disturbance as a result of climate change, are recognised as potential significant threats to habitats such as kelp, seagrass beds and saltmarshes, and could have similar ecological consequences to human disturbance (Norderhaug *et al*., 2020).

In Wales, the potential pressures of sea level rise and increased storm events as a result of climate change are managed through Shoreline Management Plans (SMPs) which been developed by NRW and relevant authority groups. These SMPs set out a strategic approach for managing the coastline from coastal flooding and erosion risk over the short, medium and long term through strategies including ‘Hold the Line’, ‘Advance the Line’, ‘Managed Realignment’, and ‘No Active Intervention’. SMPs are informed by a range of available evidence, including on climate change, and are reviewed and updated regarding new climate change projections. These plans have the potential to protect and enhance blue carbon habitats through the ‘Managed Realignment’ and potentially ‘No Active Intervention’ strategies which could offset the impact of coastal squeeze on blue carbon habitats.

Climate change is also expected to lead to an increase in sea surface temperatures, ocean acidification and hypoxia which have been predicted to negatively impact a wide range of species with the potential to sequester carbon. For example, it has been predicted that climate change will lead to significant declines in coralline algae populations (such as maerl), by up to 84% around Scotland (Simon-Nutbrown *et al.,* 2020). In addition, species distributions have the potential to change in response to changes in seawater condition. For example, warming can cause mass mortality of seagrasses and lead to local extinctions or the geographic shift of seagrass species. Ultimately, climate change may lead to changes in community structure, alter the distribution of blue carbon habitats and potentially reduce their extent and carbon sequestration potential. Human disturbance has the potential to amplify the effects of climate change by decreasing the resilience of ecosystems and making them more vulnerable to naturally occurring events such as storms (Ling *et al*. 2015).

The management measures highlighted in this report have the potential to protect and enhance blue carbon habitats and potentially increase the resilience of these ecosystems to climate change. However, the long-term effectiveness and cost-benefit of such management measures under future climate conditions remains relatively unknown.

3.1. Saltmarsh

Saltmarshes are recognised as one of the largest sinks of carbon in coastal ecosystems, and as a result a high proportion of the literature on managing blue carbon habitats is focused on this habitat. Saltmarshes vary greatly in their carbon sequestration potential, with plant community composition and sedimentary regime being key factors. For example, Ford *et al*. (2019) showed that carbon stored in saltmarshes in Wales varied between 2000 – 5800 gCm^{-2}.

There are approximately 46,000 hectares of saltmarsh around the UK, however recent decades have seen a decline in saltmarsh habitat. The primary driver of saltmarsh decline is recognised to be land claim, whereby saltmarsh is converted for other land uses such as farming, recreation, housing and development. Climate change and subsequently sea level rise also threaten saltmarshes through “coastal squeeze”, whereby erosion reduces saltmarsh size and fixed flood defences prevent migration inland.

Two types of saltmarsh habitats are listed as Annex I features under the Habitats Directive and saltmarshes (‘Atlantic Salt meadows’ and ‘Salicornia and other annuals colonising mud and sand’). Saltmarshes are also a habitat of principal importance under Section 7 of the Environment (Wales) Act 2016. There are approximately 76 km^2 of saltmarshes in Wales, with the largest extents of saltmarsh found in the Estuaries of Carmarthen Bay and Estuaries SAC.

Saltmarsh habitats can form a component of the Annex I features ‘estuaries’ and ‘large shallow inlets and bays’. The SACs that are designated for saltmarsh habitats are listed in **Table 3** along with the condition of saltmarsh (based on the indicative condition assessments) and known pressures which have the potential to impact condition or extent.

The literature review identified seven main management options for managing saltmarshes, covering the protection, restoration, and creation of saltmarsh habitats. These include:

- Management of potential pressures;
  - Water quality;
  - Grazing;
  - Access and recreation;
  - INNS;

- Habitat restoration and enhancement;
  - Sediment recharging / beneficial use of dredged material;
  - Habitat creation schemes; and
  - Replanting vegetation.

Table 3. SACs designated for Annex I saltmarsh features and the activities currently known to impact condition along with pressures currently known to or have the potential to impact condition.

SAC	Saltmarsh condition	Pressures with the potential to impact the condition of the features
Dee Estuary / Aber Dyfyrdwy	Favourable	N/A
Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd	Unfavourable	Water quality; Infrastructure maintenance; Over grazing; Vehicle access
Glannau Môn Cors Heli / Anglesey Coast: Saltmarsh	Unfavourable	Water quality; Forestry
Kenfig / Cynffig	Unfavourable	Water quality; Over grazing; Litter
Pembrokeshire Marine / Sir Benfro Forol	Unfavourable	Water quality, marine litter
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau	Unfavourable	Infrastructure development; Coastal squeeze; Over grazing
Severn Estuary / Môr Hafren	Unfavourable	Coastal squeeze; Under grazing Vehicle access

Please note: Saltmarsh at Burry Inlet has reportedly been negatively impacted by vehicle access (Tyler-Walters and Arnold, 2008).

3.1.1. Management of potential pressures

Water quality

Background

Saltmarshes are known to remove high levels of nutrients from the water, however, intense nutrient enrichment can be a driver of saltmarsh loss (Deegan *et al*., 2012). Morris and Bradley (1999) found that, after 12 years of increased nitrogen and phosphorus in a South Carolina saltmarsh, carbon in the top 5 cm of the sediment was 472 g C m^{-2} lower than in control plots, which was equivalent to a constant loss of 40 g C m^{-2} y^{-1}. Deegan *et al*. (2012) showed that nutrient levels commonly associated with coastal eutrophication can increase above-ground leaf biomass, but decreased the dense, below-ground biomass of bank-stabilizing roots, and increase microbial decomposition of organic matter. This increase has the potential to lead to less overall carbon storage (Bulseco *et al*. 2019). Similarly, results from short-term experiments by Turner *et al*. (2009) demonstrated that root and rhizome biomass and carbon accumulation is reduced with nutrient enrichment.

Wasson *et al*. (2017) showed robust linkages between increased anthropogenic nutrient loading, increased algal wrack cover, reduction in marsh resilience and conversion of marsh habitat to mudflat through bank erosion.

Potential management measures

Decreasing nutrient inputs to estuaries is considered necessary for the conservation and restoration of saltmarshes and enhancing their resilience. Reduction in eutrophication may also mitigate against the effects of sea level rise by boosting the accumulation of organic matter and increasing marsh elevation (Turner *et al*., 2009); however, more studies are needed to confirm this.

Before management measures can be implemented, the source of the pollution affecting the saltmarsh would firstly need to be identified. Management which could reduce the pressure of nutrient pollution on saltmarsh may include reducing fertilizer use in agriculture, introducing buffers of vegetation adjacent to water bodies to take up excess nutrients in run-off and controlling nutrient inputs from sewage. River Basin Management Plans are already in place throughout the UK which outline the actions needed to improve water quality in a given water body. In addition, Nitrate Vulnerable Zones under the Nitrates Directive have been designated to identify areas which are or could become polluted by nitrates. Currently, Nitrate Vulnerable Zones account for 2.4% of land in Wales. Recently, Welsh Government announced the Water Resources (Control of Agricultural Pollution) (Wales) Regulation 2021, which includes nutrient management planning, sustainable fertiliser application, manure and silage storage standards. This aims to reduce eutrophication in Welsh waters and has the potential to enhance carbon storage in saltmarshes negatively affected by diffuse water pollution.

Grazing

Background

Heavy grazing by livestock is generally considered a key threat to saltmarshes due to this having a negative impact on above-ground plant characteristics and compacting sediment; this could reduce carbon sequestration (Harvey *et al*., 2019; He *et al*., 2020). Grazing also has the potential to reduce carbon stocks over the long-term. However, low to moderate grazing can be beneficial to saltmarshes (Bouchard *et al*., 2003) and has been shown not to impact carbon soil stock (Harvey *et al*., 2019; He *et al*., 2020). Moderate grazing in Normandy, France was found to enhance plant richness and diversity compared to un-grazed or over-grazed sites (Bouchard *et al*., 2003). Grazing and artificial mowing in the Netherlands was also shown to reduce the erodibility of fine-grained soils in saltmarshes. However, in some cases, compaction by large grazers was observed to thin fine-grained layers, thus lowering the ground elevations and leaving the saltmarsh more vulnerable to sea level rise (Marin-Diaz *et al*., 2021).

Potential management measures

Management measures which reduce high levels of grazing have the potential to promote the resilience of saltmarshes and subsequently carbon storage and sequestration. Moderate grazing, by limiting numbers of livestock per unit area or rotational grazing by livestock, is often recommended (Marin-Diaz *et al*., 2021). Appropriate levels of grazing likely vary between sites and therefore studies prior to implementing management and further monitoring after management are needed to ensure the level of grazing are appropriate and benefit the saltmarsh.

Incentives are often used for managing grazing on saltmarshes in the UK. Payment schemes such as Agri-Environment Schemes (AES) have been used with the aim of compensating farmers for the loss of income through reducing stocking rates or timing restrictions (Mason *et al*., 2019). In Wales, the AES ‘Glastir’ payments between £135 and £268 per hectare per year can be issued, depending on the degree of management implemented, such as reducing levels of grazing to beneficial levels or excluding grazing altogether (Welsh Government, 2018). A study on AES schemes in the UK estimated that more than £5 million has been spent on saltmarsh grazing agreements over the last ten years, but found that the payment schemes often did not achieve the required low-moderate grazing intensity for conservation (Mason *et al*., 2019).

Mason *et al*. (2019) suggested that thorough auditing or moving to a reward scheme where payment is applied after conservation outcomes are met could be more beneficial and lead to conservation targets being met. In Wales, a comprehensive monitoring study by MacDonald *et al*. (2019) found that AES schemes in terrestrial environments had only been partially successful in maintaining and enhancing species abundance.

In addition to payment schemes, purchasing of saltmarsh from farmers could also be considered; however, this would be most cost effective where grazing intensity is high.

Grazing on saltmarshes has also been used as a management measure to attract waders and wildfowl; for example, by maintaining sward height to promote nest building. Therefore, any wider implications of implementing management measures should be fully assessed.

Access and recreation

Background

Trampling is recognised as having a potential negative impact on saltmarsh vegetation. For example, in California, USA, an experiment was carried out in the 1990s to investigate the impact of 6 months of different trampling levels on saltmarsh vegetation and the recovery over a year. Low and intermediate levels of trampling maintained a high level of *Salicornia virginica* (90%), however, bare ground dominated in heavily trampled areas. After one year of recovery, the plots had shorter *Salicornia* plants and bare patches remained (Woolfolk, 1999).

Vehicle access for intertidal fisheries can also be detrimental to saltmarshes. Damage from vehicle access on a saltmarsh in the Burry Inlet, Wales, reportedly resulted in erosion and a subsequent ditch up to 2.5 m deep along the vehicle access route. This erosion led to those accessing the shore to drive on undisturbed parts of the saltmarsh, causing further damage and erosion (Tyler-Walters and Arnold, 2008). Similarly, in North Lincolnshire, the use of quad bikes, tractors and large vehicles on saltmarshes for accessing fishing grounds resulted in severe rutting of the saltmarshes that was visible several years later (Tyler-Walters and Arnold, 2008). A review by Tyler-Walters and Arnold (2008) also summarised that whilst saltmarshes are relatively resistant to trampling by foot access, they are likely more vulnerable to vehicle access, with a single pass leading to rutting and loss of saltmarsh plants. Schofield (2016) showed that vehicle tracks on a saltmarsh in New South Wales, Australia, reduced vegetation cover by an average of 90% compared to outside of the tracks, increased soil compaction and led to localised depressions in the saltmarsh.

Potential management measures

Management measures suggested for reducing the impacts of trampling or vehicle access include voluntary closures, raising awareness of saltmarsh importance through on-site signage (Schofield, 2016). Access by vehicle is sometimes necessary, however, and vehicles are currently in use by organisation such as the Royal Society for the Protection of Birds (RSPB) to limit the effect of vehicle access on wetlands and marshes (RSPB, 2012)

Voluntary measures would likely require monitoring to ensure compliance. Management of access could also be legislative in the form of an Order within an SAC, however, implementing an order would require clear evidence to show the activity is negatively impacting SAC features.

It is important to consider that, depending on the full extent of the trampling or vehicle access, the detrimental impacts are likely to be relatively localised. Therefore, the impacts on the carbon stock and sequestration of saltmarshes due to trampling are potentially smaller than issues which cause widespread changes to saltmarshes.

Invasive non-native species

Background

Saltmarshes are known to have been impacted by the introduction of non-native alga. For example, *Gracilaria vermiculophylla* is a red alga known to have been introduced to saltmarsh habitats in the Atlantic and Pacific Oceans. Studies have suggested that this species grows rapidly and is tolerant to a wide range of environmental conditions such as extreme salinities and temperatures, high levels of light and nutrients, and grazing (Hu and Juan, 2013). Thomsen *et al*. (2009) found that saltmarsh habitats in Virginia, USA, where *G. vermiculophylla* is present, had lower species richness and biomass. This could have an impact on the carbon storage and sequestration potential of the saltmarsh.

In Wales, *G. vermiculophylla* has recently been found in the Dwyryd Estuary, forming mats in saltmarsh pans and has been assessed as a moderate risk by the GB Non-native Species Secretariat (JNCC, 2019a).

In Europe, the invasive clonal grass *Elymus athericus* has been shown to affect saltmarsh communities and biodiversity since introduction in the 1990s. In Mont Saint Michel Bay, France, a study by Valéry *et al*. (2004) found that this species increased the trapping of carbon within the saltmarsh sediments compared to areas where the non-native was not present.

Potential management measures

Management of non-native flora is often focussed on the physical and mechanical removal of the species, through manipulations of native species or the use of grazers; however, attempts result in mixed success (Gray and Jones, 1977; Smith, 2016). The early detection and a rapid response can increase success in eradicating such non-natives and, to facilitate this, regular monitoring is needed.

3.1.2. Habitat restoration and enhancement

Sediment recharging / beneficial use of dredge material

Background

Sediment recharge is the process where dredged marine sediments are placed in such a way to create intertidal habitats and are commonly used to create saltmarshes or protect habitats from erosion. Sea-level rise as a result of climate change is one of the main threats to saltmarshes, and those which have low elevation or that have accretion rates which are slower than the rate of sea-level may benefit the most from the deposition of dredged material (O'Donnell *et al*., 2018). Creating or increasing the resilience of saltmarshes has the potential to increase blue carbon capture and storage.

Potential management measures

There are four recognised ways in which dredged material can be used (Adnitt *et al*., 2007a). These are:

- Recharge of low-lying land to raise elevations prior to managed realignment;
- Direct recharge of existing saltmarsh to raise elevations for plant colonisation;
- Water column recharge (subtidal) to reduce erosion of intertidal areas; and
- Foreshore placement to reduce coastal erosion and raise mudflat elevations.

In the US, dredged material has been used for decades to both restore and create saltmarshes and has proved successful particularly for raising saltmarsh elevation and increasing saltmarsh resilience (French, 2018; O'Donnell *et al*., 2018). Saltmarshes typically trap fine-grained sediments and thus fine-grained dredge material have the potential to be most effective. However, sediment geochemistry and contamination need to be assessed prior to use to ensure it is suitable for deposition on the saltmarsh (O'Donnell *et al*., 2018).

In the UK, over 20 intertidal recharge projects have been undertaken. Two projects in Essex (Allfleet's Marsh and Trimley Marsh) are managed realignment schemes which included the beneficial use of dredged sediment as land forming materials prior to breaching the sea walls (MMO, 2019). The direct placement of material onto the subtidal in order to elevate an area into the intertidal, and thus create saltmarsh, has never been practiced in the UK (MMO, 2019).

Beneficial or 'alternative' use projects using fine/silt sediments can be costly and technically challenging in terms of appropriate timings and getting permission. Several initiatives are being undertaken to address barriers to implementation in order to facilitate the beneficial use of sediment. For example, the RSPB's SEABUDS project (Ausden *et al*., 2018), and the Solent Forum's BUDS project (The Solent Forum, 2021).

The use of sediment recharge schemes requires careful planning as the depositing of such material may cause smothering of habitats or aquaculture sites and cause navigational hazards in inshore waters (Adnitt *et al*., 2007a).

Costs in the US vary widely and will depend on the location and scale of the project. Estimated costs are in the region of £12,000 - £38,000 per hectare (converted from values in French *et al*., 2018). A recent review of UK beneficial use costs indicated that both costs and benefits of intertidal sediment recharge projects were highly site specific (ABPmer, 2017). Projects where double handling was required tended to be the most expensive, whereas those where materials could be discharged directly from the vessel which had undertaken the dredging tended to be less expensive, and potentially cost neutral (when compared to taking the materials to a licensed disposal ground). This is for example the case at Lymington (Hampshire), where Lymington Harbour Commissioners beneficially dispose of some of their materials every winter without incurring additional costs; noting that this is creating a raised mudflat feature rather than saltmarsh (though the feature facilitates better protection of the saltmarsh behind) (ABPmer, 2020). Conversely, also at Lymington, at the Wightlink Boiler Marsh saltmarsh recharge, which required double handling, pumping and the installation of retention structures, costs were very high, at £550,000 for 1 ha of restoration (over two campaigns in 2012 and 2013) (ABPmer, 2017).

Habitat creation schemes

Background

Several schemes have been used in order to create saltmarsh habitats, including managed realignment, manipulation of natural processes by using obstructions or sediment polders, and Regulated Tidal Exchange (RTE). These schemes have been identified as potential measures which could greatly increase the blue carbon stores around the UK. This is due to the high levels of carbon sequestration and storage provided by saltmarsh habitats. Mapping of flood plains has also highlighted areas where creation of saltmarsh could be undertaken in Wales through managed realignment (Armstrong et al., 2021a).

Potential management measures

The creation of saltmarshes by managed realignment is undertaken by controlled breaching of coastal defences such as sea walls and embankments, allowing seawater to flood previously defended land, and create new intertidal habitat. Managed realignment schemes are one of the most popular measures for creating intertidal habitats, with over 120 completed managed realignment projects across northern Europe and some 80 projects completed in the UK over the last 30 years, including several in Wales (ABPmer, 2021).

Generally, managed realignment schemes have been successful in establishing saltmarshes which have been shown to enhance the blue carbon value of an area. Burden *et al*. (2019) investigated carbon sequestration rates at nine recreated saltmarshes in the UK ranging from 4 to 116 years old. They found that carbon sequestration was rapid in the first 20 years (average of 104 gC $m^{-2}yr^{-1}$) before slowing down to a steady rate thereafter (average of 64 $gCm^{-2}yr^{-1}$). High rates of sequestration have also been observed soon after saltmarsh creation in the Bay of Fundy, Canada. Six years after a controlled breach of two dykes, the carbon burial rate in the restored marsh was 5 times more than the rate for mature marsh (1,329 $gCm^{-2}y^{-1}$) (Wollenberg *et al*., 2018).

Whilst carbon sequestration rates in created saltmarshes can be similar to established sites, it can take prologued periods of time to achieve similar values of carbon soil stock. For example, 15 years after the Tollesbury managed realignment in Essex, it was found that soil carbon stock, the carbon/nitrogen ratio and below-ground biomass all remained more similar to the agricultural site rather than mature saltmarshes (Burden *et al*., 2013). Burden *et al*. (2013; 2019) estimated that it could take approximately 100 years for restored sites to accumulate the amount of carbon currently stored in the established sites. However, this research did not fully account for the fact that managed realignment sites can often accrete rapidly with sediment, and that it is this function which can lead to very large amounts of carbon being stored in the soil, particularly during the initial post breach years (ABPmer, 2021). It was estimated from ten managed realignment sites around England that the blue carbon sequestration of saltmarshes can vary between sites (from 221 – 1,849 $gCm^{-2}yr^{-1}$), with sites which are low-lying or in sediment rich estuaries holding more carbon due to higher sediment accretion rates. The highest value was determined for the Steart managed realignment scheme, which is located on the very turbid Parrett estuary. Similarly, high rates for the Steart scheme were also found by Mossman *et al*. (2021), who calculated that 4,850 tC had been stored here every year in the first 4 years post implementation, equating to 1,940 gC $m^{-2}yr^{-1}$.

It is important to ensure sites are appropriately designed for saltmarsh creation, for example, consideration is needed regarding factors such as wave energy, elevation, sediment accretion and drainage.

The Welsh Shoreline Management Plans (SMPs) predicted that coastal squeeze is likely to impact a range of saltmarshes between 2005 – 2025. Plans are already in place to compensate for this loss through the creation of new saltmarsh habitats (NRW, 2018). Measures such as managed realignment, which can be expensive but generally successful at creating saltmarsh habitats, are often used to alleviate the pressures of coastal squeeze on saltmarsh habitats with new saltmarshes also acting as natural coastal defences.

RTE involves the controlled exchange of estuarine or coastal waters onto a previously terrestrial site using a variety of exchange structures (sluices, culverts or weirs), rather than breaches, to control the tidal exchange volumes and the extent of flooding. Over 25 RTE projects have been undertaken in the UK, however they are generally small-scale. A recent larger scale project was undertaken in 2018 on Wallasea Island, Essex, covering 132 hectares (MMO, 2019).

The manipulation of natural processes covers a wide range of techniques such as introducing obstructions or altering shorelines. Generally, structures are placed in wave exposed areas in order to provide erosion protection and/or enhance the natural accretion of sediment, with the aim of elevating land and mitigating coastal flooding. The latter technique is often referred to as ‘sedimentation polders’ (low lying areas of land surrounded by physical barriers such as brushwood fences); these have been used along the Dutch and German Wadden Sea coasts for decades to create saltmarsh in front of coastal defences (MMO, 2019). A Welsh example can be found at Rumney Great Wharf east of Cardiff; here, five polders measuring 13.5 ha were installed in 1999 and 2005. These are thought to have been partially successful in leading to a modest increase in saltmarsh area at this location, though a lack of maintenance has meant that the polders are no longer functioning properly, as most of the brushwood and many fence posts have been eroded (Armstrong *et al*., 2021b). It should be noted that saltmarsh expanded by 3 ha after the polders were installed; however, how much of this was due to the polders is difficult to determine as no monitoring was undertaken (Armstrong *et al*., 2021b).

The costs associated with these schemes are highly variable depending on the scale and location of the proposed works. For managed realignment projects around the UK, prices have ranged from between £850 – £156,000 per hectare (Armstrong *et al*., 2021b). Managed realignment usually requires the purchase of land (generally agricultural) which can represent a high proportion of the total cost. The Environment Agency (2015) estimated this could cost 80-85% of the total restoration cost, but could change depending on location. Sedimentation polder costs are rarely reported. It is known that the 2005 Rumney Great Wharf works (for four polders) cost £190,000 (£290,000 in 2020 prices; this equates to £202 m^{-1}). All of these schemes would likely have costs associated with continued management, maintenance and repair of the site once the scheme has been implemented. This is particularly the case with regularly inundated structures such as brushwood fences or groynes. For example, brushwood bundles tend to last between 3 and 8 years. They are particularly rapidly eroded in exposed locations, where movement induced by tidal currents and waves leads to the branches rubbing against each other, which makes them brittle more quickly (Armstrong *et al*., 2021b).

Replanting vegetation

Background

Natural colonisation is generally considered to be the preferred option for saltmarsh restoration, although planting or seeding could be used where natural recolonisation is deemed not possible (Adnitt *et al*., 2007a), or where greater plant species diversity is desired (Mossman *et al*., 2020).

Potential management measures

In 1998 at Chichester Harbour, England, the Chichester Harbour Conservancy transplanted sprigs of *Spartina* sp. at 0.3-0.6 m intervals at the site of a former car park approximately 450 m^2 in size. Large stones were used to prevent continued car parking in the area. Two months after planting, 100% survival was recorded with the sprigs having grown and developed seed heads (Adnitt *et al*., 2007b). However, the long-term effectiveness and scale of replanting vegetation to restore saltmarsh is unknown.

3.1.3. Potential management in Welsh SACs

Based on the known pressures which have the potential to affect saltmarsh and associated blue carbon storage and sequestration in Wales, potential management measures for Welsh SACs are listed in Table 4, along with wider ecosystem benefits and feasibility of implementation.

Table 4. Blue carbon management actions for saltmarsh in Welsh SACs, the wider ecosystem benefits, feasibility of management approach to manage saltmarsh in Welsh SACs along with potential SACs where management could be implemented.

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Improve water quality	Increased biodiversity; establish potential nursery grounds; reduced erosion	Medium. The source of the pollution must first be identified then management could enforce regulations or provide incentives to reduce sewage outflows and eutrophication.	Evidence; multiple benefits; preventative action	Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd Glannau Môn Cors Heli / Anglesey Coast: Saltmarsh Kenfig / Cynffig Pembrokeshire Marine / Sir Benfro Forol
Reduce grazing activity	Improved species richness in birds and plants	High. Grazing has successfully been controlled at several sites by establishing incentives for farmers.	Adaptive management; scale; collaboration & engagement; preventative action	Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd Kenfig / Cynffig Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau
Reduce access and recreation	Reduced disturbance to birds and mammals; reduced trampling	High. Measures may need to be legislative (as well as voluntary) but monitoring of compliance would be recommended. Physical	Adaptive management; scale; collaboration & engagement; public	Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
	pressure on non-target habitats and species	barriers and clear signage could also be used.	participation; evidence; multiple benefits; long-term; preventative action	Severn Estuary / Môr Hafren
Manage invasive non-native species	Reduce competition with native species; improve native species richness and biomass	Low. Biosecurity most effective approach; management action is often ineffective once species are established.	Multiple benefits; preventative action	More research needed
Sediment recharging	Create or extend saltmarsh habitat; increase bird and fish diversity; create natural coastal flood barrier; provision new habitats for colonization; improve coastal resilience to environmental change	Medium. Evidence of success exists; however site-specific surveys are required to ensure suitability. Requires suitable sediment source, detailed assessments, stakeholder engagement and consenting.	Scale; multiple benefits; long-term; building resilience	Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Severn Estuary / Môr Hafren

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Habitat creation	Create or extend saltmarsh habitat; increased diversity of fish and bird species; create a natural coastal flood barrier; provision new habitats for colonisation	Medium. Evidence of success exists such as managed realignment; however, feasibility is site-dependent, and often requires purchasing of land, complex assessments, stakeholder engagement and consenting.	Scale; multiple benefits; long-term; building resilience	Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Severn Estuary / Môr Hafren
Replanting vegetation	Create or extend saltmarsh habitat; increased species diversity	Medium. Success depends on physical and biological conditions at sites. Natural recolonisation preferred.	Scale; long-term; building resilience	Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Severn Estuary / Môr Hafren

3.2. Seagrass

Seagrasses are a marine flowering plant that form large beds of grass-like meadows in the intertidal and subtidal areas. Seagrass meadows are recognised as a key blue carbon habitat globally due to high rates of sequestration from sediment accumulation, photosynthesis and subsequent carbon burial. The loss of seagrass beds is known to lead to the reduction of carbon accumulation and in addition, seagrass loss can lead to erosion of the underlying sediment carbon stocks due to increased wave velocity and height (Marbà *et al*., 2015).

In the UK, seagrass is considered nationally scarce, with up to 92% of seagrass lost over the last century; this has been attributed to disease, poor water quality, coastal development, fishing gear and other human disturbances (Stewart and Williams, 2019).

Seagrass beds are a habitat of principal importance in Wales under Section 7 of the Environment (Wales) Act 2016. Seagrass beds are also listed as threatened and declining under OSPAR. In Wales, there are approximately 7.3 km^2 of mapped seagrass beds (Armstrong *et al*., 2021a), and beds are often located within designated sites. Seagrass beds can constitute a component part of Annex I features such as 'estuaries', 'large shallow inlets and bays' and 'mudflats and sand flats not covered by seawater at low tide', however, seagrass beds are not an Annex I feature in their own right. The SACs features which provide protection for seagrass are listed in **Table 5** along with the condition and pressures known to impact condition.

Porthdinllaen, in Pen Llŷn a'r Sarnau SAC, has one of the largest and densest seagrass beds in north Wales and more than 90 moorings have been counted within and around these seagrass beds (Hargrave, *undated*). Other notable seagrass beds exist within the Pembrokeshire Marine / Sir Benfro Forol and Severn Estuary SACs. In addition, seagrass is listed as a designated feature in nine SSSIs, including Milford Haven Waterway and the Traeth Lafan SSSI.

Table 5. SACs where seagrass beds are known to occur and the condition of the respective Annex I features along with pressures currently known to or have the potential to impact condition.

SAC	Annex I features which protect seagrass beds	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd	Mudflats and sandflats	Unfavourable	Water quality
Pembrokeshire Marine / Sir Benfro Forol*	Estuaries	Unfavourable	Water quality

SAC	Annex I features which protect seagrass beds	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Pembrokeshire Marine / Sir Benfro Forol*	Large shallow inlets and bays	Unfavourable	Water quality; bait digging; INNS; Mooring and anchoring; Fisheries (trawling)
Pembrokeshire Marine / Sir Benfro Forol*	Mudflats and sandflats	Unfavourable	Water quality; bait digging
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau	Estuaries	Unfavourable	Water quality; Infrastructure and development
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau	Large shallow inlets and bays	Favourable	Fisheries (dredging)
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau	Mudflats and sandflats	Unfavourable	Water quality; Infrastructure and development; bait digging; INNS; Vehicle use
Severn Estuary / Môr Hafren	Estuaries	Unfavourable	Water quality
Y Fenai a Bae Conwy / Menai Strait & Conwy Bay SAC	Mudflats and sandflats	Favourable	Water quality; INNS; fisheries; Bait collection; Fish/shellfish collection; Mooring and anchoring; Vehicle use

The conservation and restoration of this key blue carbon habitat has been conducted for over 50 years, globally. The main techniques used to protect and restore seagrass habitats include:

- Management of potential pressures;
  - Water quality;
  - Fishing;
  - Access and recreation;
  - Invasive non-natives;
  - Pathogens and disease; and
- Habitat restoration and enhancement;

- Restoration through replanting or reseeding.

3.2.1. Management of potential pressures

Water quality

Background

Seagrasses are sensitive to degraded water quality and conditions which impose light limitations to photosynthesis (Orth *et al*., 2006a). Eutrophication has also been shown affect turbidity by increasing phytoplankton and macroalgae blooms which shade seagrass and reduce productivity and the depth penetration of seagrass. Marbà *et al*. (2015) investigated carbon stocks in Oyster Harbour, Western Australia, where 80% of seagrass beds were lost between 1960s-1990s due to eutrophication and siltation. Cores from bare (but previously vegetated areas) and a reference vegetated area which survived disturbance showed that seagrass disappearance had led to a loss of 1.5 kg C m^{-2}, equivalent to 60 years of carbon deposition. Equally, loss of seagrass led to an overall reduction in carbon sequestration in the harbour.

Potential management measures

Projects promoting the natural recolonisation of seagrass tend to focus on water quality improvements, with the assumption that once suitable conditions are established, seagrass will naturally recolonise. Management measures could involve efforts to upgrade sewage systems, implement programmes to identify and control discharges from industrial, residential and agricultural areas in the coastal zone. The potential increase in seagrass extent as a result of a reduction in pollution may enhance the habitats' sequestration of carbon and over time increase the carbon soil stock. It is worth noting however that seagrass beds mainly expand via their rhizomes, and thus natural recolonisation can take a fairly long time, and will require at least some beds to be present nearby.

Managing nutrient enrichment has been shown on several occasions to positively impact seagrass beds. In Tampa Bay, Florida, wastewater controls implemented in the 1980s resulted in a 60% reduction in nitrogen load compared to the mid-1970s. This led to an increase in seagrass coverage in the bay, with coverage in 2008 being the highest recorded since 1950s (Greening *et al*., 2011). Similarly, 40 years of anthropogenic nutrient pollution from in Mumford Cove, Connecticut, led to the absence of seagrass in the bay. After ceasing of the wastewater outfall, seagrass beds expanded to cover over a third of the cove within 10 years and, after another 5 years, seagrass was present across half of the cove (approximately 22 ha) (Vaudrey *et al*., 2010).

Fishing

Background

Fishing activities such as the use of towed demersal gear are known to negatively impact seagrass beds (NRW, 2016b). Neckles *et al*. (2005) investigated the effects of trawling for blue mussels *Mytilus edulis* on seagrass beds in Maquoit Bay, USA, and the recovery after trawling ceased. Impacted sites ranged from 3.4 to 31.8 ha in size and were characterized by the removal of above and below ground plant material from the majority of the seabed. The study found that, one year after the last trawl, seagrass shoot density, shoot height, and total biomass averaged 2-3%, 46-61% and < 1% respectively to that of the reference sites. Substantial differences in seagrass biomass persisted between disturbed and reference sites up to 7 years after trawling. Rates of recovery depended on initial fishing intensity, but the authors estimated it would take more than 10 years for seagrass shoot density to match pre-trawling standards. It can therefore be assumed that bottom fishing activities could have a negative impact on carbon storage and sequestration due to the damage and removal of seagrass. It is likely that the effects of towed demersal gear, such as beam trawl gear, on seagrass beds are greater than the damage caused by anchoring and moorings, which would be more localised.

Potential management measures

Due to the known importance of seagrass beds as nursery grounds for commercial species, the use of bottom fishing gears has often been prohibited near seagrass beds. The EU Mediterranean fisheries Article 4(1) of Regulation No. 1967/2006, for example, prohibits fishing with trawl nets, dredged, seins or similar nets above protected habitats such as seagrass beds. At the request of a Member State, the European Commission may allow a derogation from Article 4(1) (European Commission, 2021). Calls have been made to further protect Mediterranean seagrass habitats after studies have shown that 1,568 hours of fishing took place over seagrass beds in 2019 (Oceana, 2020).

In England, under the Marine Coastal Access Act 2009, Southern Inshore Fisheries and Conservation Authority (IFCA) introduced the Bottom Towed Fishing Gear Byelaw to prohibit activities over a total of 27.8 km^2 of habitats around the Hampshire coastline in order to protect vulnerable habitats, some of these overlapping with seagrass beds. In 2014, Devon and Severn IFCA implemented the Mobile Fishing Permit Byelaw to prohibit demersal towed gear from impacting seagrass beds within the Torbay Marine Conservation Zone and Lyme Bay to Torbay SAC (Devon and Severn IFCA, 2017). A permit is required for vessels operating within the Authority's District.

Seagrass beds are also permanently closed to northern prawn trawling in Northern Australia in a management area between Queensland to Cape Londonderry (6000 km of coastline). This is a habitat protection measure to preserve seagrass beds as an important nursery ground (Commonwealth of Australia, 2013).

Due to the statutory nature of such measures, compliance will likely be high particularly where monitoring is in place. Consequently, such measures would likely lead to the protection of the carbon stored and sequestered by seagrasses.

Access and recreation

Background

It is widely known that moorings can have a negative effect on seagrass beds. Unsworth and Cullen-Unsworth (2015) investigated the effects of physical disturbance on seagrass meadows in Porthdinllaen within the Pen Llyn a'r Sarnau SAC. They concluded that the chains and anchors associated with various types of moorings dragged over the seagrass and repeatedly tore the plants, eventually ripping up their roots and rhizomes and reducing the capacity for recovery to occur. At Rottnest Island, Australia, the deployment of moorings since the 1930s had led to an average loss of 4.8 kg C m^{-2} by 2009 that had accumulated in 50 cm-thick, 200-year-old deposits. The undisturbed meadows contained up to 2-fold higher amounts of fine sediments (<0.125 mm) compared to mooring scars, suggesting that the loss of organic carbon resulted from both direct scouring of sediments and re-suspension and subsequent loss of fine-grained sediments (Serrano *et al*., 2016).

The presence of the moorings reduces seagrass density within a limited area around each mooring; however, the locations of moorings can vary from year to year, and this has the effect of displacing the areas of impact from one year to the next. As a result, the areas impacted by each mooring may actually be quite extensive when multiple years are considered (Unsworth and Cullen-Unsworth, 2015).

As seagrass beds can also occur within the intertidal zone, they can also be susceptible to the impacts of disturbance from onshore activities such as bait digging, shellfish gathering and trampling (Travaille *et al*., 2015; Garmendia *et al*., 2017). Garmendia *et al*. (2017) found that shoot density and subsequently seagrass abundance in northern Spain was negatively affected by trampling and digging. Similarly, Pauls *et al*. (2017) investigated the impact of vehicle access on seagrass at Angle Bay, Wales, and the timescale for recovery after one impact event. The immediate disturbance of one tyre track led to an 80-90% decrease in seagrass blade frequency localised to the track. The seagrass took 2 years to fully recover after the tyre tracks caused compression of the sediment and local changes in hydrology.

Eckrich and Holmquist (2000) recorded up to 72% loss of seagrass root (rhizome) biomass and up to 81% loss of standing crop of plant material as a result of trampling at some seagrass beds in Puerto Rico. The reduced seagrass cover in heavily trampled sample areas was visually distinguishable from the surrounding seagrass 14 months after the trampling ended. Whilst trampling may be considered to be a low impact activity, it can nevertheless give rise to significant negative effects on sensitive habitats within MPAs (Travaille *et al*., 2015), and loss of seagrass cover has the potential to have a negative impact on the carbon sequestration and storage potential of seagrass beds.

Potential management measures

There are an increasing number of case studies in the UK where moorings have been adapted to reduce contact with the seabed and seagrasses, known as 'eco-moorings'. In Studland Bay, Dorset, 10 eco-moorings are being deployed which use a helical screw anchor which is driven into the seabed and attached to a surface mooring buoy with an elasticated rod (The Seahorse Trust, 2021). In Salcombe, Devon, the eco-mooring consists of small floats which are used to suspend the chain of traditional swing moorings above the seabed (Luff *et al*., 2019). The mooring modifications and installation costs of the Salcombe eco-mooring were considered substantially lower than for alternative designs, costing a minimum of 67% less than alternative eco-mooring designs on the market (estimates of £1,620 - £3,200 for components, and installation costs of £600) (Luff *et al*., 2019).

Luff *et al*. (2019) studied the effect of the eco-mooring in Salcombe, Devon, on the underlying seagrass beds. They found that 3 years after the deployment of the eco-mooring, seagrass density surrounding the modified mooring was over twice as high as that of the standard mooring, with blade length surrounding the modified mooring also found to exceed that of the standard mooring. Parry-Wilson *et al*. (2019) undertook an investigation of the behavioural responses of recreational boaters to eco-moorings in a popular anchorage area in Torbay, Devon, and found that incentives should be considered to encourage behavioural change towards the use of eco-moorings. These incentives could include complimentary use of public eco-moorings and/or charging fees for anchoring privileges in protected areas. Fees collected from potential charges could be used to improve policing of byelaws in protected areas, as well as funding the maintenance and further deployment of eco-moorings.

In Wales, the seagrass bed at Porthdinllaen, Wales, has more than 90 moorings positioned within and in close proximity of the bed (Hargrave, *undated*). Aerial images and dive surveys have shown that these moorings have adversely impacted the seagrass beds (Morris *et al*., 2009; Stamp and Morris, 2012; Unsworth and Cullen Unsworth, 2015). The recent Porthdinllaen Seagrass project aims to develop and implement eco-moorings (Hargrave, undated).

Voluntary No-Anchor Zones (VNAZ) have been used to protect seagrass beds. In the Helford River, Cornwall, a VNAZ has been in place since 2009 which has been mostly successful and seen the expansion of the seagrass bed. ‘No Anchor’ signs were originally placed on traditional block and chain moorings above the seagrass bed, however, a rope mooring with a midway submerged buoy to keep the slack line off the seagrass was designed (Helford Voluntary Marine Conservation Area (VMCA), 2017). The Helford VMCA raised £2,500, with most of the cost going on hardware and the remainder going on education and awareness. Similarly, a voluntary 'no anchoring' zone is also in place in Milford Haven in order to reduce the direct physical impact of anchoring on both seagrass and maerl beds (see Section 3.4.1 for more detail).

Similarly, in Milford Haven, such as near Angle Bay and Gelliswick Bay, seagrass has been noted to be adversely affected by anchoring and mooring (Burton, 2013); therefore, moorings have been positioned with the aim to discourage boat users from anchoring in the seagrass beds (MHPA, 2015). Similarly, in 1992, a no anchoring zone in the Skomer MCZ was implemented through the use of marker buoys to prevent anchoring in the seagrass beds. Signs with clear maps around the area are in place to encourage compliance; these are considered to have been successful. Visitor mooring were also put in place around Skomer to discourage anchoring (Newman et al., 2017).

It could be expected that the use of management measures such as eco-moorings and voluntary closed areas would improve the extent and condition of seagrass beds, subsequently leading to an increase in carbon sequestration and storage. However, this measure should be coupled with raising awareness, including the use of clear signage and potentially the use of incentives in order to facilitate change in the behaviour of boaters.

Bait digging on the foreshore is known to occur on the lower shore where seagrass beds can occur. Bait digging can be managed through a range of legislative (orders and byelaws) and voluntary measures, through measures such as full, partial or seasonal area closures. Partial closures of sites to prevent damage to seagrass beds from activities including bait digging are relatively common. For example, parts of the Humber Estuary is closed to bait digging and fishing activities under local authority byelaws for the protection of seagrass habitats (North Eastern IFCA, 2019). Similarly, Southern IFCA manage hand gathering, including bait digging, through a byelaw to protect seagrass beds from damage from digging and trampling (Southern IFCA, 2021). Also, collection of bait in the Morecambe Bay SAC is prohibited in the closed seagrass areas without written authorisation (North Western IFCA, 2014).

At Traeth Melynog on Anglesey, Wales, access to the cockle fishery is managed through a permit system administered by Welsh Government under the Cockles and Mussels (Specified Area) (Wales) Order 2011. All permit holders are required to comply with specific access arrangements defined by NRW in order to avoid impact on the seagrass bed. Under the National Nature Reserve byelaws, NRW issues a permit annually which gives permission for collectors to follow an access route, including vehicle access up to a specific point, around the seagrass bed (Welsh Government, 2019). It has been noted, however, that there is evidence of vehicle use outside of the permitted area, suggesting lack of compliance (Kay and Morris-Webb, 2017). However, this fishery has been temporarily closed since November 2021 (until further notice) to conserve and protect cockle stocks (Welsh Government, 2021b).

The benefits of managing access or bait digging on carbon stocks and sequestration are unknown, however, they can be assumed to be reflective of the extent and intensity of the disturbance of the seagrass beds. Whilst the impact of these activities on carbon stock and sequestration are likely to be smaller than from more widespread activities such as demersal trawling, mooring or pollution, their management across several locations has the potential to lead to a degree of benefit.

Other measures have been applied to prevent unregulated vehicle access on the foreshore (Buckley *et al*., 2004). For example, at Angle Bay, Wales, large blocks of stone (more than 1 m^3) have been placed at the top of the shore to stop vehicle access (Kay and Morris-Webb, 2017). Similarly, restricting the location or time that vehicles can be used, or raising awareness through educational campaigns, codes of conduct or signposts could be attempted to reduce impacts (Buckley, 2004).

Invasive non-native species

Background

Seagrass are known to have been impacted by non-native algae. *Sargassum muticum* is a widespread non-native brown alga in the UK which can outcompete seagrass due to its rapid growth and its presence can lead to a decline in seagrass abundance through shading and abrasion. It has been found that seagrass may also facilitate the presence of *S. muticum* by providing a structure for settlement (Tweedley *et al*., 2008). The presence of *S. muticum* has been shown to alter the composition and abundance of epibiota found on the blades of seagrass (DeAmicis and Foggo, 2015). Studies have also suggested that dense mats of the red algae *G. vermiculophylla* can shade seagrass and inhibit growth and affect survival (Hu and Juan, 2013). Carbon sequestration by seagrass beds could be negatively impacted where seagrass growth and abundance is hampered by the presence of *S. muticum* or *G. vermiculophylla*. However, the contribution these invasive alga plays towards blue carbon storage and sequestration in comparison to seagrass beds is relatively unknown.

Potential management measures

Management of non-native flora is often focussed on the physical and mechanical removal of the species, through manipulations of native species or the use of grazers, however, attempts result in mixed success (Gray and Jones, 1977; Smith, 2016). Whilst physical removal of algae is possible, *S. muticum* spreads incredibly easily through both sexual and asexual reproduction (through the release of fronds) and therefore care is needed to prevent further spread during removal. Due to the widespread nature of *S. muticum* and its ability to reproduce and colonise new areas with ease, it is likely that eradication schemes would be unsuccessful and not cost-effective. Between 1973 and 1976, when *S. muticum* was newly established in England, eradication programmes organised in Portsmouth and on the Isle of Wight saw the removal of *S. muticum* using tractors fitted with harrows and hand collections. During one year, some 450 tonnes of *S. muticum* were removed; however, all attempts at eradication were reported as largely unsuccessful (Gray and Jones, 1977).

It is recognised that early detection and rapid responses can increase success in eradicating non-natives and, to facilitate this, regular monitoring is needed. Where a non-native is already widespread, eradication would be difficult and potentially impossible.

Pathogens and disease

Background

Declines in seagrasses around the globe have been attributed to diseases from pathogens such as *Labyrinthula* sp. This 'wasting disease' causes brown or black spots and lesions to spread across the leaf, limiting photosynthetic activity, and is spread through waterborne introductions, blade-to-blade contact and floating leaf detritus (Sullivan *et al*., 2013). Large-scale loss of seagrass beds due to disease (and potentially poor water quality) in the north Atlantic were reported in the 1930s which had detrimental effects on local fauna, fisheries and waterfowl populations (Orth *et al*., 2006b; Sullivan *et al*., 2013). In the UK, substantial degradation of seagrass beds occurred and since then, reports of seagrass losses due to disease are regularly made (Green *et al*., 2020). Reduction in photosynthetic activity and mass mortality of seagrass beds could lead to the reduction of carbon storage and sequestration in seagrass habitats.

Climate change and eutrophication are expected to increase outbreaks of disease in seagrasses due to increased stress and reduced resilience of seagrass.

Potential management measures

Managing the impact of diseases on seagrass beds is likely to involve increasing the resilience of seagrass through alleviating potential pressures and increasing extent. The presence of disease could also hamper current and future efforts to manage pressures and/or restoring seagrass. Regular monitoring programmes could be used to assess seagrass condition and identify areas where disease is prevalent.

3.2.2. Habitat restoration and enhancement

Replanting or reseeding vegetation

Background

Schemes to restore seagrass through habitat replanting and reseeding vegetation have grown in popularity in recent years and mapping has shown areas in the UK where opportunities for restoration may exist (Armstrong *et al*., 2021a). In 2021, the Seagrass Restoration Handbook was published with the aim to provide practical guidance on the restoration and conservation of seagrass beds in the UK and Ireland (Gamble et al., 2021). As seagrass beds are recognised as a key blue carbon habitat, their restoration has the potential to increase blue carbon capture and storage.

Potential management measures

Restoration of seagrass beds has often been undertaken through the replanting or reseeding of seagrass. The replanting of adult shoots usually involves harvesting plants from an existing meadow and transplanting them to the restoration site once suitable conditions have been established for seagrass survival. Aquaria or nursery-grown seagrasses have also been used for translocation. Replanting of seagrasses often uses labour-intensive diving techniques for planting various sizes and ages of seagrass plants into new localities. It is often necessary to anchor the shoots to the seabed in order for them to take hold. Many forms of planting methods including stapling, use of anchored and unanchored sprigs, plugs, peat pots, and transplanting of individual mature plants have been trialled at various locations (Phillips, 1980; Fonseca, 1994; Fonseca *et al*., 1998), with varying success. Less intensive methods which do not require diving have been used to restore seagrass through replanting. For example, the ‘Save the Bay’ restoration project in Narragansett Bay, New Hampshire, in the US used a specialised remote transplant methodology "Transplanting Eelgrass Remotely with Frames" (TERF). The TERF method involved using clusters of plants temporarily tied with degradable crepe paper to a weighted frame of wire mesh. The “Shell Method” is another successful seagrass transplanting method in which oyster shells are used as an anchoring device and does not require diving for subtidal transplanting (Park and Lee, 2007). Fertilization of transplants to accelerate growth has also been trialled, however, the benefits in seagrass restoration projects have been inconclusive (Fonseca, 1994).

The use of reseeding generally relates to the collection and targeted redistribution of wild seeds. Methods for reseeding have included the simple broadcasting of seeds by hand from a small vessel (Orth *et al*., 2012) or attaching seeds to a biodegradable tape and placing it below the sediment surface (Churchill *et al*., 1978).

In Dale Bay, Pembrokeshire, as part of the Sky Ocean Rescue, WWF and Swansea University restoration project (Project Seagrass), the BoSSline (Bags of Segrass Seeds Line) method was used, whereby volunteer snorkellers and divers collected seeds from existing meadows around the UK. The seeds were then cultivated at Swansea University and 100 seeds placed into individual sand-filled hessian bags which were tied at metre intervals to a rope which was dropped onto on the seafloor in Dale Bay (Unsworth *et al*., 2019). It is expected that the natural materials used in the planting process will safely disintegrate over time, leaving the seagrass seedlings to take root and grow (Swansea University, 2020). A trial study by Unsworth *et al*. (2019) found that 94% of the bags deployed developed mature seagrass shoots, with 2.4 ± 2.4 mature shoots per bag after 10 months. However, the establishment rate of individual seeds was low at 3.5%, though typical of this species and comparable to other studies. Where conditions are suitable for seagrass, there is the potential that seagrass beds will increase in their extent after being restored, based on natural recruitment.

Replanting and reseeding has been shown to increase seagrass extent and in turn increase carbon sequestration. For example, in Virginia, US, a $2 million project aimed to reseed 125 ha of coastal lagoon sediment through hand broadcasting between 1999 and 2010 (Orth *et al*., 2012). This restoration led to an increase in the extent of seagrass beds which covered more than 1,700 ha over ten years as a result of natural dispersal from the reseeded areas. This restoration has led to an increase in carbon sequestration, with a total of 15,000 t of carbon being sequestered in the sediment since 1999 (Reynold *et al*., 2016). Modelling by Reynold *et al*. (2016) estimated that natural recovery of seagrass could take more than 100 years to reach the coverage achieved by using seeds in just 10 years. Marbà *et al*. (2015) found that carbon burial rates increased with the age of the revegetated sites, and 18 years after planting, they were similar to those in continuously vegetated meadows (26.4 ± 0.8 g m^{-2} $year^{-1}$). This suggests that revegetation can effectively restore seagrass carbon sequestration capacity over the long term.

It is important to note that seagrass restoration projects can often be unsuccessful. Generally, failures are due to suboptimal habitat conditions and the continuation of stressors which may have caused the original seagrass loss (such as eutrophication). Before undertaking replanting or reseeding of seagrass beds, consideration is needed regarding the number of seeds or plants, the location and environmental conditions and the potential need for the removal of existing pressures. A global review by van Katwijk *et al*. (2016) found that survival and population growth rate of restored seagrass is positively affected by the number of seeds or plants initially planted as opposed to the method of planting or species of seagrass. In the US, reseeding and replanting techniques have sometimes been used together and, using seeds possibly in conjunction with adult plants may in some instances prove more effective (van Katwijk *et al*., 2016).

Seagrass restoration has the capacity to be both very expensive and have a high risk of project failure, with seagrass restoration costs higher than terrestrial plant restoration (Kenworthy *et al*., 2018). Bayraktarov (2016) quote median to average per-hectare costs of between £88,000 and £322,000 for seagrass restoration (2020 prices) (Armstrong *et al*., 2021a). Project Seagrass' Dale project cost around £200,000 to implement (so £100,000 per hectare). This value does, however, exclude many volunteer hours and provisions for monitoring (Project Seagrass, pers. comm.; Gamble et al., 2021).

3.2.3. Potential management in Welsh SACs

Based on the known pressures which have the potential to affect seagrass beds and associated blue carbon storage and sequestration in Wales, potential management measures for Welsh SAC are listed in **Table 6**, along with wider ecosystem benefits and feasibility of implementation.

Table 6. Blue carbon management actions for seagrass beds in Welsh SACs, the wider ecosystem benefits, feasibility of management approach to manage seagrass beds in Welsh SACs along with potential SACs where management could be implemented.

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Improve water quality	Improved water quality; increased biodiversity; establish nursery grounds	Medium. The source of the pollution must first be identified then management could enforce regulations or provide incentives to reduce sewage outflows and eutrophication.	Multiple benefits; preventative action	Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Severn Estuary / Môr Hafren Y Fenai a Bae Conwy / Menai Strait & Conwy Bay SAC
Reduce fishery activities	Habitat resilience; Increased biodiversity; Establish nursery grounds; improve water quality	Medium. Fishing activities can be managed within SACs; however, it is often most effective when stakeholders are engaged, and compliance monitoring undertaken	Collaboration and engagement; multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Y Fenai a Bae Conwy / Menai Strait & Conwy Bay SAC
Reduce disturbance from moorings and	Increased species diversity; Reduced disturbance on other species	High. UK-based evidence of eco-mooring adoption and associated seagrass recovery. Measures may need to be	Collaboration and engagement; public participation;	Pembrokeshire Marine / Sir Benfro Forol

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
anchors / access and recreation		legislative (as well as voluntary) but monitoring of compliance would be recommended. Physical barriers and clear signage could also be used.	multiple benefits; preventative action	Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Y Fenai a Bae Conwy / Menai Strait & Conwy Bay SAC
Manage invasive non-native species	Reduce competition with native species; improve native species richness and biomass	Low. Biosecurity most effective approach, management action is often ineffective once species are established.	Multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Y Fenai a Bae Conwy / Menai Strait & Conwy Bay SAC
Manage / investigate pathogens and disease	Improve species abundance; Habitat resilience	Low. It is difficult to eradicate diseases; however, increasing resilience to disease could be increased by managing existing pressures.	Multiple benefits; preventative action	More research is needed to assess extent and prevalence of disease in seagrass beds

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Replanting or reseeding for restoration	Habitat provision; increased biomass; Establish nursery ground	Medium. Restoration efforts have been successful but may fail due to poor habitat choice or continuation of pressures.	Scale; multiple benefits; long-term	More research is needed for site selection

3.3. Kelp

It has been suggested that kelp forests can assimilate enough carbon to contribute substantially to primary production in coastal waters off the UK and Ireland (Smale *et al.*, 2013). Kelp predominately grows on hard or mixed sand and rock substrates where there is little potential to lead to long-term carbon burial. However, vegetated coastal habitats such as kelp forests have been identified as important carbon sinks (Krause-Jensen and Duarte, 2016). Recent studies have found that the above-ground biomass in kelp is an important source of carbon exported as detritus to other ecosystems, such as the deep coastal areas, the continental shelf and slope (Smale *et al.*, 2018; Kokubu *et al.*, 2019). In addition, the carbon stored in vegetation such as kelp can also be consumed by invertebrates and other fauna, which can facilitate the transfer of carbon within marine food webs and the export of detrital carbon (Pessarrodona *et al.*, 2018).

In Wales, kelp forests cover the majority of the Welsh coastline and typically form part of the Annex I 'reefs' feature. They can also be found within the features 'large shallow inlets and bays' and 'estuaries'. Reefs are one of the primary reasons for the designation of SACs. The SACs which are designated for 'reefs' features are listed in **Table 7** along with the condition and pressures known to impact condition.

Burrows *et al*. (2014) stated that kelp populations were declining in subtidal and intertidal areas of the UK, but that a lack of field-based research on the anthropogenic pressures impacting kelp was impeding the implementation of conservation and management (Burrows *et al*., 2014). However, no noticeable declines in kelp have been recorded in Wales.

Table 7. SACs designated for the Annex I 'reefs' feature, the indicative condition of the features along with pressures currently known to or have the potential to impact condition.

SAC	Annex I reefs feature condition	Pressures with the potential to impact the condition of the features
Cardigan Bay / Bae Ceredigion	Favourable	Water quality; Shellfish gathering; Access and recreation
Pembrokeshire Marine / Sir Benfro Forol	Unfavourable	Water quality; Potting; INNS; Industrial Development
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau	Unfavourable	Water quality; Historic fishing damage
Severn Estuary / Môr Hafren	Unknown	Unknown
Y Fenai a Bae Conwy / Menai Strait and Conwy Bay	Favourable	Water quality; INNS; Fish/shellfish/seaweed gathering

It is recognised that the management and restoration of kelp could help maintain carbon storage rates of kelp forests. The management and restoration of kelp forests has typically followed two broad strategies, thus includes:

- Management of potential pressures;
  - Water quality;
  - Fisheries;
  - Invasive non-native species and
- Habitat restoration and creation;
  - Restoration through replanting.

3.3.1. Management of potential pressures

Water quality

Background

Evidence of the impacts of pollution, particularly sewage, on kelp communities is lacking in the UK. The effects of pollution, such as from sewage outfalls, on kelp communities has been shown outside of the UK. For example, in Sydney, Australia, untreated sewage outfalls led to the local extinction of native kelp (crayweed) forests in the 1980s. In addition, the decline of kelp forests off Los Angeles was considered to be due to increasing pressure from sewage discharges (Foster and Schiel, 2010). Mortality of kelp has the potential to reduce the contribution kelp makes towards the capture of carbon through photosynthesis.

Potential management measures

Some evidence suggests that kelp could be negatively impacted by pollution, therefore it could be assumed that management aimed at reducing the levels of pollution in the water column could benefit kelp populations. Overall, however, as relatively little is known about the impact of pollution on kelp, more work is needed to assess appropriate management measures.

Fishing

Background

One of the main issues which can lead to the clearance of kelp forests is fishing, particularly from trawling activities. As well as the loss of carbon storage potential from loss of kelp forests, kelp clearance from trawling can lead to multiple ecological consequences, such as the direct removal of food, diminished biogenic structure and indirect effects via altered fish assemblages (Norderhaug *et al*., 2020). Research by Lorensten *et al*. (2010) in Norway showed that mechanical dredging for kelp since the 1970s led to 92% fewer young commercial fish in harvested areas.

Potential management measures

There are few examples of management being implemented to protect loss of kelp beds. However, a byelaw has recently been implemented in Sussex, England, with the aim to alleviate fishing pressure specifically to allow recovery and protection of kelp forests after a 95% reduction in kelp from fishing, storm damage and poor water quality since the 1980s. This byelaw was agreed by the Sussex IFCA in January 2020 and approved by the Secretary of State for the Environment in March 2021. This has seen trawling excluded from 304 km² of Sussex coastline year-round, where no trawling is allowed within 4 km of the shore. In addition to protecting vital fish breeding, feeding and nursery grounds to safeguard future inshore fisheries, the natural restoration of kelp could help combat climate change by producing more biomass carbon for sequestration (mostly in other habitats/areas) and reducing coastal erosion by absorbing wave energy and provide a haven for wildlife (Sussex IFCA, 2020). Continual monitoring is due to take place to assess the effectiveness of the byelaw on kelp recovery.

The exclusion zone under the Sussex IFCA byelaw has been estimated to cost businesses £90,000 per year. The exclusion of the trawlers is however expected to reduce bycatch of bass, leading to an estimated £150,000 worth of bass being available for the wider fishery per year. The compliance and enforcement of such restrictions and ongoing monitoring is considered to be of high importance for ensuring effective implementation. As such, Sussex IFCA will also monitor the exclusion zone through land and sea-based patrols and joint-agency working/monitoring and research, which is estimated to cost £20,000 per year (Sussex IFCA, 2020).

Another recent management project of dredging in kelp forests is the Sustainable Inshore Fisheries Trust (SIFT) ‘Help the Kelp’ campaign in Scotland, which aimed to ban industrial scale dredging of kelp forests. As a result, mechanical dredging for harvesting purposes was banned by the Scottish Parliament in 2018 (SIFT, 2018).

Invasive non-native species

Background

Some evidence suggests that kelp forests could be affected by non-native species. In the Salish Sea, USA, Britton-Simmons (2004) found that native kelp abundance was lower where non-native alga *S. muticum* was present, likely do to shading. There is currently limited evidence to suggest invasive species such as *S. muticum* are impacting kelp in UK waters.

The non-native kelp species *Undaria* sp. is present in UK waters; however, there is no evidence to suggest this species negatively impacts native kelp. It is believed this species occupies different environmental conditions to native kelp. A clearance experiment by Epstein (2019) showed that, although *Undaria* sp. recruited into these cleared areas first, native kelp species (*Laminaria digitata*) recovered and this led to a decline in the *Undaria* sp.

Little is known about the contribution these invasive non-native species make towards blue carbon in comparison to native kelp species.

Potential management measures

Eradication of non-native kelp species has been shown to be expensive but generally successful. In New Zealand, removal of *Undaria* sp. using heat treatment over 15 months led to the successful removal of an isolated population on a wreck. However, this cost approximately £200,000 (Wotton *et al*., 2004). In Tasmania, *Undaria* sp. was removed from an 800 m^2 area of rocky reef; however, although abundance decreased, full eradication was not successful (Hewitt *et al*., 2005). Early detection and rapid response can increase the success of eradicating non-natives and, to facilitate this, regular monitoring is needed. Where a non-native is already widespread, eradication would be difficult and potentially impossible.

Ultimately, more research is needed into the potential impacts of invasive non-native species on kelp in UK waters before the need for management measures can be assessed.

3.3.2. Habitat restoration and enhancement

Replanting vegetation

Background

The restoration of kelp forests through replanting is a relatively new concept; however, it has the potential to both increase the capture of carbon along with providing improved nursery grounds for juvenile fish species, increasing species diversity and helping to reduce the effects of coastal erosion.

Potential management measures

Transplanting techniques include relocating adult or juvenile kelp plants (sporophyte life stages) from a donor site onto the substratum. It can also include, at greater cost, rearing them from seed/zygote stages in the laboratory and planting them into the field.

In Australia, restoration of kelp has been successful through the replanting of kelp forests. After improvements in wastewater infrastructure and water quality were made (which led to the initial decline in kelp) project Operation Crayweed began, which aimed to restore kelp (crayweed, *P. comosa*) through transplanting adult plants from nearby forests. Despite survival varying between restoration sites, survival of transplanted kelp was considered comparable to natural mortality. In 2019, transplanted kelp had begun reproducing, leading to multiple generations of kelp, often expanding hundreds of meters from the original restored patches. These restored kelp forests have become self-sustaining without the need for additional cost or maintenance. The initially relatively small-scale active restoration has led to kelp populations continuing to expand and colonize substantial areas, thus beginning to function as natural forests (Marzinelli *et al*., 2016; Layton *et al*., 2020). The costs associated with replanting kelp were estimated at around US\$570 m^{-2} (equivalent to £460 m^{-2}), which covered the cost of the dive team, boat and basic equipment and consumables. In addition, it was estimated substantial additional costs would be needed for project management, monitoring (Layton *et al*., 2020).

The installation of hard substrata has also been used for kelp restoration, for example artificial reefs, which have been shown to be successful at increasing kelp recruitment over short time scales (Terawaki *et al*., 2001). For example, Layton *et al*. (2019) successfully transplanted >500 adult kelp (*Ecklonia radiata*) on artificial reefs in Tasmania in 2014. Survivorship of transplants was comparable to natural reefs, and abundant recruitment of juveniles ensured that many patches became self-sustaining. Crucially however, only patches above a certain size and density of adult kelp facilitated adequate recruitment to maintain the kelp canopy, illustrating the potential importance of minimum patch sizes and densities when transplanting kelp.

Restoration of kelp has not always been successful. Sanderson *et al*. (2003) used a variety of techniques in an attempt to restore kelp forests in Tasmania, including transplanting juvenile kelp, transplanting kelp growing on artificial substrata and laying rope seeded with lab-grown juvenile kelp. However, there was only marginal success over the short term with no populations surviving over the long term (Layton *et al*., 2020). This was attributed to the unsuitability of some artificial substrata for kelp colonization and the potential effects of other colonizing organisms (for example filamentous turf algae, mussel, and barnacles) on kelp recruitment.

Currently, in the North East of England, the ‘Stronger Shores – Marine Habitats Protecting Communities Project’ is a project which aims to investigate the use of nature-based solutions as a means to manage coastal erosion and flooding whilst increasing biodiversity. The project aims to investigate the potential of restoring kelp, seagrass and oysters beds along the North East Coast and its potential effectiveness for mitigating coastal erosion and flooding.

Fredriksen *et al*. (2020) tested a new approach to kelp restoration termed “green gravel”. This comprised seeding small granite rocks with kelp (*Saccharina latissima*) and rearing them in the laboratory until they grew to 2–3 cm in length, before planting on rocky reefs. This green gravel was deployed outside Flødevigen Research Station, in southern Norway. The replanted kelp had high survival and growth over 9 months. Over many months green gravel deployed in open plots remained in place, and started to attach to the underlying reef, even if covered with turf algae. This technique was described as efficient and cost-effective at US\$7 m^{-2} and not requiring scuba diving or trained fieldworkers as the green gravel was dropped from the surface. However, this project was undertaken on a relatively small scale and over a short period of time and the success of this technique on large scales over the long term is currently unknown.

As described by Layton *et al*. (2020), kelp restoration has so far only been undertaken on small to medium scales (not at the large-scale that loss can occur). Increasing the scalability of kelp forest restoration to the seascape-scale remains a considerable challenge, especially in the face of climate change. Furthermore, costs of restoration operations can be high due to diver labour and so increasing automation / efficacy of mass seeding techniques is desirable. These examples highlight the importance of removing existing pressures prior to costly restoration projects where appropriate

3.3.3. Potential management in Welsh SACs

Improving the condition of reefs could be assumed to benefit kelp, therefore potential management measures for different Welsh SACs have been determined in Table 8 based upon the pressures which have the potential to affect the ‘reefs’ feature.

Overall, relatively little is known about the pressures specifically affecting kelp and their carbon storage in UK waters. Before management measures can be effectively determined for protecting kelp forests, evidence is needed on the effects of known pressures, such as fishing activities and water quality on the extent and quality of the kelp forests within Welsh SACs. Such evidence may also highlight areas which could benefit from restoration through replanting techniques.

Table 8. Blue carbon management actions for kelp in Welsh SACs, the wider ecosystem benefits, feasibility of management approach to manage kelp in Welsh SACs along with potential SACs where management could be implemented.

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Improve water quality	Improved water quality; Increased biodiversity	Medium. The source of the pollution must first be identified then management could enforce regulations or provide incentives to reduce sewage outflows and eutrophication.	Multiple benefits; preventative action	Cardigan Bay / Bae Ceredigion Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Y Fenai a Bae Conwy / Menai Strait and Conwy Bay
Reduce fishery activities	Increased biodiversity; Increased ecosystem resilience; Establish nursery grounds; Coastal protection	Medium. Fishing activities can be managed within SACs; however, it is often most effective when stakeholders are engaged and compliance monitoring undertaken.	Collaboration and engagement; evidence; multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau Y Fenai a Bae Conwy / Menai Strait and Conwy Bay

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Manage invasive non-native species	Reduce competition with native species; improve native species richness and biomass	Low. Biosecurity most effective approach, management action is often ineffective once species are established.	Multiple benefits; preventative action	Y Fenai a Bae Conwy / Menai Strait and Conwy Bay
Replanting for restoration	Habitat provision; Increased biomass; Establish nursery grounds; Coastal protection	Low. Only small to medium scale attempts have been made, some successful attempts have used artificial reefs.	Multiple benefits; long-term; building resilience	More research needed for site selection

3.4. Maerl beds

Maerl is a slow growing coralline algae which forms a habitat that is known to support high levels of biodiversity, act as nursery grounds for juvenile commercial fish and contain high densities of broodstock bivalves (Hall-Spencer *et al*., 2003; Kamenos *et al*., 2004). Maerl has the capacity to sequester and store large volumes of blue carbon (Mao, 2020). Maerl beds store organic carbon in their tissues from photosynthesis and inorganic carbon in their calcium carbonate skeletons, which becomes stored in the seabed over the long term once the maerl dies and is buried (Mao, 2020). It has been suggested that maerl beds can store substantial quantities of carbon in the underlying sediments, with a comparable storage capacity to (if not higher than) vegetated systems such as saltmarsh and seagrass habitats (Burrows *et al*., 2017). They also have the capacity to store carbon for millennia (van der Heijden and Kamenos, 2015).

Growth rates of European maerl species range between tenths of a millimetre to 1 millimetre per annum (Bosence and Wilson, 2003). Due to its slow growth, recovery of maerl from damage has been categorised by OSPAR as ‘poor’ meaning that only partial recovery of maerl beds is likely within 10 years and full recovery may take up to 25 years. However, maerl beds may never recover if a bed is removed by dredging activities or smothered by sediment (Bordehore *et al*., 2003; Hall-Spencer *et al*., 2010). OSPAR have recognised that further management measures are needed within the north-east Atlantic to prevent the loss of maerl beds from human activities (OSPAR, 2019).

Maerl is listed as an Annex V habitat and live maerl is present in Wales within the Pembrokeshire Marine SAC, in the Milford Haven Estuary. Patchy maerl beds have also been recorded in the Lleyn Peninsula and the Sarnau SAC around St Tudwal’s Islands (JNCC, 2021). The maerl bed in the Milford Haven Estuary is thought to be approximately 2,000 years old (Blake, 2005). In 2005, the extent of this maerl bed was estimated to be approximately 1.5 km^2 in total, with 0.5 km^2 of live maerl (Bunker and Camplin, 2005). However, the refurbishment of the South Hook Liquified Natural Gas jetty in Milford Haven led to an 83% decline in live maerl between 2005-2010 (Bunker, 2011). By 2016, it was estimated that live maerl cover had reduced by up to 92% since 2005, to 0.36 km^2 (JNCC, 2019b).

Maerl is included within Annex I habitats ‘estuaries’ and the ‘large shallow inlet and bay’ feature of the Pembrokeshire Marine SAC, which are currently in unfavourable condition. The SACs features which protect maerl beds habitats are listed in **Table 9** along with the condition of the features and known issues or risks which have the potential to impact condition.

The main management measures for maerl beds focus on the protection of maerl from damage or deterioration as a result of pressures. This includes:

- Management of potential pressures;
  - Water quality;
  - Fishing;
  - Access and recreation; and
  - Invasive non-native species.

Table 9. SACs where maerl beds are known to occur and the condition of the respective Annex I features along with pressures currently known to or have the potential to impact condition.

SAC	Annex I feature protecting maerl beds	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Pembrokeshire Marine / Sir Benfro Forol	Estuaries	Unfavourable	Water quality
Pembrokeshire Marine / Sir Benfro Forol	Large shallow inlets and bays	Unfavourable	Water quality, Industrial development; Fisheries (trawling); Mooring and anchoring; INNS

Please note: Fishing with bottom trawls (with less than four metre beam size) has been known to occur within the vicinity of maerl (NRW, 2016c) and slipper limpets are well established on maerl beds in Milford Haven and have led to an increase in sedimentation at this site (Cole and Baird, 1953; JNCC, 2019b).

3.4.1. Management of potential pressures

Water quality

Background

Water pollution, such as from sewage pollution or eutrophication, has been known to directly impact maerl beds. This is predominately due to an increase in sediment loads or due to the growth of ephemeral macroalgae species around maerl beds. For example, in the Bay of Brest, France, maerl beds situated under sewage outfalls had an increase in dead maerl and maerl burial, decrease in live maerl density, and reduced species richness compared to reports from 50 years previously (Grall and Glémarec, 1997; Hall-Spencer *et al*., 2010).

Organic pollution from aquaculture can impact maerl habitats through the deposition of organic material (Hall-Spencer *et al*., 2006). Hall-Spencer *et al*. (2006) showed that maerl beds below salmon farms in Scotland experienced build-up of waste organic matter during slow water flows which became trapped within the maerl thalli. Farms which had existed for 4 to 12 years were observed to have caused long-term damage by killing the maerl. The deposition of detritus and fine sediments from mussel aquaculture also led to the burial and subsequent deterioration of Galician maerl beds in northwest Spain (Peña and Bárbara, 2008). Hall-Spencer *et al*. (2006) suggested that the presence of maerl habitats should be taken into account in the development of regulation for fish farm authorisations, to avoid negative impacts on maerl beds.

Water turbidity caused by particles suspended or dissolved in water can also affect maerl beds through reducing light availability for photosynthesis. Turbidity is already a key factor limiting the depth that maerl can exist at. Changes to turbidity can be caused by excess nutrients, for example from sewage outfalls, which increases phytoplankton growth and reduces light availability. Such changes may have a detrimental impact on maerl growth and survival and consequently blue carbon storage and sequestration.

Potential management measures

Management measures such as controlling or ceasing sewage outfalls in close proximity to maerl beds would likely allow the slow recovery of maerl beds where live maerl still exists. In addition, assessments of whether proposed aquaculture sites are in close proximity to maerl beds should be undertaken prior to them being constructed, to ensure no impacts of smothering on the maerl beds. There are currently no known examples of pollution management specifically to protect maerl habitats. However, such management measures have the potential to protect and enhance maerl extent and increase blue carbon storage and sequestration.

Fishing

Background

Bottom fishing activities, such as trawling or dredging, have been shown to have negative effects on maerl beds. Hall-Spencer and Moore (2000) investigated the long-term impacts of scallop dredging on maerl habitats in Scotland. They found that, 4 years after the initial disturbance, fauna associated with maerl beds had not recolonised the trawl tracks, and crushed/compacted maerl was buried under the sediment surface. They also found that dredging killed the surface layer of living thalli upon which the habitat depends. Although many species associated with maerl communities are small or burrow deeply enough to survive the passage of fishing gear, dredging reduces the biodiversity and structural complexity of the maerl.

Wilson *et al* (2004) recognised that burial of maerl, especially in fine or anoxic sediments, was lethal or caused significant stress and hence concluded that trawling is one of the main threats to live maerl. Fishing adjacent to maerl beds could also have a negative impact due to smothering, depending on the extent and frequency of the activity and the hydrodynamics in the area of the habitat, and consequently impact its blue carbon potential.

Potential management measures

Fisheries management has been implemented specifically to prohibit scallop dredging on maerl beds, such as in Brittany, France, and in Shetland, UK. The Shetland Shellfish Management Organisation (SSMO) has prohibited dredging within any area that contains biogenic reef, including maerl and horse mussels (Cappell *et al*., 2018). In Wales, scallop dredging is banned in Milford Haven under the Scallop Fishing (Wales) (No. 2) Order 2010, which has banned the use of towed fishing gear within 1 nautical mile from the Welsh coastline. This ban has indirectly protected the maerl bed from scallop dredging, where the activity was known to take place previously (JNCC, 2019b).

Within Milford Haven, including where maerl beds occur, the Welsh Government Byelaw 39 currently limits the size of beam trawls to 4 m; however, an assessment by NRW (2016c) concluded that impacts from smaller beam sizes would likely cause the same initial damage to maerl beds. Additional restrictions on bottom fishing gear in Milford Haven, such as a complete ban, has the potential to fully protect the maerl bed from this threat. However, evidence would be needed to fully assess the effects that continued trawling is having on the maerl beds, in order to implement further restrictions. To ensure the management measure is effective, regular compliance monitoring and enforcement would also be needed.

There are economic benefits as well environmental and blue carbon benefits to be gained from protecting maerl grounds from bottom fishing, such as providing important feeding areas for juvenile commercial fish or to protect brood stocks of commercial bivalve species (Hall-Spencer *et al*., 2003).

Access and recreation

Background

Similar to seagrass, anchoring and mooring chains can directly affect maerl beds through abrasion and smothering, which in turn leads to mortality and a potential loss of blue carbon stores.

Potential management measures

In 2011, a voluntary 'no anchoring' was implemented in Milford Haven, in order to reduce the direct physical impact of anchoring on both maerl and seagrass beds (Stewart and Williams, 2019). The Voluntary Agreement for the Protection of Sensitive Habitat Zones of Subtidal Seagrass and Maerl in Milford Haven was set up by the Milford Harbour Users Association (MHUA) and Pembrokeshire Marine SAC Relevant Authorities Group (RAG) (Port of Milford Haven, 2016). The effectiveness of this measure is unknown, likely due to a lack of compliance monitoring (JNCC, 2019b).

Invasive non-native species

Background

In Brittany, France, the presence of the non-native slipper limpet *Crepidula fornicata* has been shown to have led to the decline in the condition of maerl beds. Dense aggregations of the slipper limpet formed on top of the Breton maerl beds, trapping high levels of silt, faeces and pseudofaeces which have smothered and killed live maerl (Grall and Hall-Spencer, 2003).

Slipper limpets are well established on maerl beds in Milford Haven and have led to an increase in sedimentation at this site (Cole and Baird, 1953; JNCC, 2019b).

Potential management measures

Management measures such as the mechanical removal of slipper limpets has been attempted. In Wales, slipper limpets were successfully removed through manual clearance of all infected blue mussel beds in the Menai Strait and Conwy Bay SAC in 2007 and 2008 (following accidental introduction in 2006). This was deemed successful due to the rapid nature of the eradication, and the direct link with shellfish culture facilities which enabled wholesale removal of contaminated mussel lays. Such eradication methods may not be directly transferable to natural habitats. Recorded of slippers limpets were recently recorded in 2020 in the southern end of the Menai Strait suggesting arrival either through natural dispersal or accidental introduction (NRW, 2021a).

Dredging as a form of removal has also been undertaken in Brittany; however, as dredging involves the removal of the surface layer of sediment, it may impact maerl habitats more severely than proliferation of the gastropod (Grall and Hall-Spencer, 2003). This is due to dredging having long-term impacts on maerl communities by killing the surface layer of living thalli (Hall-Spencer and Moore, 2000).

The use of slipper limpets as fresh or live bait is an offence in the UK (Schedule 9 of the Wildlife and Countryside Act) and was implemented in order to manage the spread of slipper limpets around the coastline (MMO, 2015). Campaigns to raise awareness of the negative impacts of non-natives such as the ‘clean, check dry’ initiative can aid in reducing the local spread of non-natives (NRW, 2021b); however, if the non-native is already established, it can be difficult to eradicate and manage.

Eradication of marine non-native species, once established, is often deemed ineffective and not cost-efficient; thus slipper limpets may present an unmanageable threat to maerl beds once established (Grall and Hall-Spencer, 2003).

3.4.1. Potential management in Welsh SACs

Based on the known pressures which have the potential to affect maerl beds and associated blue carbon storage and sequestration in Wales, potential management measures for Welsh SACs are listed in Table 10, along with wider ecosystem benefits and feasibility of implementation.

Table 10. Blue carbon management actions for maerl in Welsh SACs, the wider ecosystem benefits, feasibility of management approach manage maerl in Welsh SACs along with potential SACs where management could be implemented.

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Improve water quality	Improved water quality; Increased biodiversity; Establish potential nursery grounds	Medium. The source of the pollution and increased turbidity must first be identified then management could enforce regulations or provide incentives to reduce sewage outflows and eutrophication.	Multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol
Reduce fishery activities	Increased biodiversity; Protection of feeding areas for juvenile fish and brood stocks of commercial species	Medium. Fishing activities can be managed within SACs; however, it is often most effective when stakeholders are engaged, and compliance monitoring undertaken.	Collaboration and engagement; multiple benefits	Pembrokeshire Marine / Sir Benfro Forol
Reduce disturbance from moorings and anchors / access and recreation	Increased species diversity; Reduced disturbance on other species	Medium. UK-based evidence of eco-mooring adoption and compliance for the protection of other habitats. However, little information on success exists for maerl. Measures may need to be legislative (as well as voluntary) but monitoring of compliance would be recommended. Physical barriers and clear signage could also be used.	Collaboration and engagement; public participation; multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Manage invasive non-native species	Reduce competition with native species; Reduce smothering effects on native species	Low. Biosecurity most effective approach, management action is often ineffective once species are established.	Multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol

3.5. Shellfish beds

Shellfish, in particular bivalves, form biogenic reefs which provide a vital habitat for a range of marine species. In addition, bivalves can act as a carbon sink through the storage of carbon for their carbonate shells (although CO_2 is released into the atmosphere during this shell biosynthesis) and carbon storage into underlying sediment from accumulation of organic matter. Carbon sequestration has therefore been recognised as a potential ecosystem service of shellfish reef restoration projects (Grabowski and Peterson, 2007; zu Ermgassen *et al*., 2021). Around the UK, bivalve populations such as horse mussels *Modiolus modiolus* and native oyster *Ostrea edulis* populations have declined over recent decades, with native oyster population having decreased by over 95%, largely as a result of overharvesting.

Shellfish beds are estimated to cover approximately 15.7 km^2 of the Welsh seabed (Armstrong *et al*., 2020). Horse mussels account for 8.7 km^2, whilst blue mussels account for 6.9 km^2 and discord mussels 0.16 km^2. Native oyster beds in Wales are scarce and only cover approximately 0.01 km^2 (Armstrong *et al*., 2020).

Horse mussels, blue mussels, discord mussels and native oysters are listed as species of principal importance under Section 7 of the Environment (Wales) Act 2016. Horse mussels form part of the Annex I feature ‘reefs’, and Llyn Peninsula and the Sarnau SAC is the only Welsh European Protected Site to contain horse mussel reefs (NRW, 2019). The reef is currently in unfavourable condition due to historical fishing damage (NRW, 2018). Although no new impacts to the reef have been found since 2012, historic trawl marks were still present in 2017 (NRW, 2018).

Native oysters are considered to be a component of the ‘estuaries’ and ‘large shallow inlets and bays’ feature within SACs and are known to occur within Milford Haven (Pembrokeshire Marine SAC). Notable populations of native oysters also occur in Swansea Bay (Woolmer, 2019). The unfavourable condition of ‘large shallow inlets and bays’ in the Pembrokeshire Marine SAC has been in part attributed to the decline in native oyster numbers (NRW, 2018).

The SACs and features which protect horse mussel and shellfish beds are listed in Table 11 , along with the condition of the features and known issues or risks which have the potential to impact condition.

Management measures for bivalves such as oysters and mussels include:

- Management of potential pressures;
  - Water quality;
  - Fishing;
  - Invasive non-native species;
  - Disease; and
- Habitat restoration and enhancement;
  - Reseeding and translocating shellfish.

Table 11. SACs where horse mussel and native oyster beds are known to occur and the condition of the respective Annex I features along with pressures currently known to or have the potential to impact condition.

SAC	Annex I feature protecting shellfish beds	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Pembrokeshire Marine / Sir Benfro Forol (Native oysters)	Estuaries	Unfavourable	Water quality
Pembrokeshire Marine / Sir Benfro Forol (Native oysters)	Large shallow inlets and bays	Unfavourable	Water quality; INNS; Fishing (trawling); unknown decline in oyster numbers; Disease
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau (Horse mussels)	Reefs	Unfavourable	Water quality; Historical fishing damage

Please note: Slipper limpets are well established in Milford Haven and have led to an increase in sedimentation at this site (Cole and Baird, 1953; JNCC, 2019b) and *Bonamia* has been recorded as present in native oyster beds in Milford Haven

3.5.1. Management of potential pressures

Water quality

Background

Bivalves, particularly native oysters, are known to be resilient to moderate levels of eutrophication, however, urban and industrial pollution has been known to negatively impact oyster stocks.

Potential management measures

Tri-butyl tin (TBT) is known to reduce growth and reproduction in native oysters. The prohibition of TBT-based anti-fouling paints worldwide came into force by the International Maritime Organisation (IMO) in 2008. Oyster growers believe this has benefitted oyster populations (Laing *et al*., 2006). Currently, the only source of TBT in the marine environment is from historical contamination in the sediments of estuaries and harbours which can be resuspended into the water from activities such as construction and dredging (Nicolaus and Barry, 2015). However, in the UK, works which impact the seafloor are strictly assessed for potential contamination release during environmental assessment, to avoid resuspended contaminated material entering the water.

Fishing

Background

Heavy fishing activity has been identified as a cause for the decline in bivalve reefs in UK waters (Thurstan *et al*., 2013). Over harvesting can lead to the depletion of bivalve stocks, and fishing through trawling and dredging of bivalve beds can lead to the physical damage of reefs, as well as degrade the habitats upon which bivalves rely (Thurstan *et al*., 2013). Some bivalves are particularly vulnerable, such as the native oysters and horse mussels, which are relatively long-lived species with often sporadic reproductive events (Laing *et al*., 2005).

Potential management measures

After management schemes to restore horse mussel beds in Strangford Lough, Northern Ireland, were deemed unsuccessful in 2014 (Geraldi *et al*., 2014), the Northern Irish authorities focussed on protecting the beds by strengthening and enforcing existing regulations on fishing which came into operation in 2013 (Department of the Environment and Department of Agriculture and Rural Development (DAERA), (Northern Ireland), 2015). For example, fishing using trawls and dredges was banned in Strangford Lough and two Sea Fishing Exclusion Zones were created where fishing below 10 m is prohibited, with the aim of providing total protection to horse mussel communities from sea fishing (DAERA, 2012). In addition, populations sited just outside the Lough, but which are considered to facilitate larval recruitment for the Lough itself, have been given protection. There are also permits for potting and limits on mooring, anchoring and diving. A fishing officer and warden post have both been created. Monitoring surveys in 2019 indicated that natural recovery through protection and monitoring had been successful, with new bed structures appearing, and greater general biodiversity having been observed (Armstrong *et al*., 2021a).

Horse mussels are present around the north coast of Wales round the Llyn Peninsula and Anglesey (NRW, 2019). The Sea Fish (Specified Sea Areas) (Prohibition of Fishing Method) (Wales) Order 2012 was put in place specifically to protects the horse mussel beds in these areas; this prohibits the use of bottom towed gear such as scallop dredges and beam trawls (Welsh Government, 2012). Although no new impacts of fishing have been observed, historic trawl marks were still present after five years and recovery could potentially take an additional 25 years (NRW, 2018).

The recent Essex Native Oyster Restoration Initiative is a collaboration between local fishermen, conservation groups, government and academia to restore native oysters in Essex estuaries (ENORI, 2022). The Blackwater, Crouch Roach and Colne Marine Conservation Zone (MCZ) was established by the ENORI members in 2013 and is the first and only area in the UK to be protected for native oysters and the habitat they provide. The Kent and Essex IFCA implemented a byelaw in 2009, which introduced a permit scheme, with permits costing £150 per year. This byelaw also specifies a maximum vessel size of 10 m, an oyster minimum landing size of 70 mm, a maximum permitted catch of 250 kg per harvesting trip, and a 200 ha no-take area (Kent and Essex IFCA, 2018).

Invasive non-native species

Background

The non-native slipper limpet is known to directly compete with native oysters for space and food, and its pseudofaeces may smother oysters (Perry and Tyler-Walters, 2016). Where slipper limpets are already abundant, such as in Milford Haven where oyster populations have been previously lost, natural recolonisation of bivalves may be difficult due to a lack of space available for settlement of spat.

Potential management measures

In general, raising awareness of the negative impacts of non-natives and promoting campaigns such as the 'clean, check dry' initiative, can aid in reducing the local spread of non-natives by recreational water users (NRW, 2021a). However, once a non-native species is established, it can be difficult to eradicate and manage.

Managing non-native species through historical oyster bed cleaning known as 'harrowing' has been suggested as a means to clear areas overrun with slipper limpets, to increase the availability of substratum for oyster settlement (Harding *et al*., 2016). This could involve breaking up slipper limpet beds, leaving broken shells which are a natural substratum for oyster settlement. However, not much is known about the success of harrowing as a management measure, with one study finding that native oyster settlement is no different between harrowed and unharrowed areas (Bromley *et al*., 2016). Consideration is also needed as to whether the crushing of slipper limpets may lead to a release of slipper limpet reproductive material into the water column and promote recruitment. Potential harrowing options would likely require a HRA to be carried out. Harding *et al*. (2016) estimated that harrowing to reduce slipper limpets in the Solent, England, could cost approximately £25,000 over 5 years (approximately £28,000 in 2020 when accounting for inflation).

Pathogens and disease

Background

The disease Bonamiosis, caused by the parasite *Bonamia ostreae,* has severely impacted native oyster populations in Europe. It has for example led to mass mortalities of over 80% and decreased production of native oyster fisheries in France by 93% (Laing *et al*., 2006). This disease is recognised as one of the biggest threats to restoring native oyster stocks in Europe (Laing *et al*., 2006). Mass mortality of shellfish beds has the potential to reduce carbon stock and sequestration in the underlying sediment.

Potential management measures

Controlled Areas have been used in New Zealand as a biosecurity measure to minimise the spread of *Bonamia ostreae* within oyster populations. This includes restriction on moving different bivalve species out of a 'Contained Zone' (northern coast on the South Island) where the disease is known to persist and restrictions on taking bivalve species into 'Protected Zones' (southern coast of the South Island, and Stewart Island). In addition, controls on moving equipment such as boats, ropes, lines and marker buoys into protected zones are also in place (Ministry for Primary Industries, 2021). Regular testing is required to monitor the potential spread of the disease. It was deemed that the most cost-effective biosecurity response in the long term was to attempt to eradicate *Bonamia ostreae* (Culloty *et al*., 2020). Thus, in response to regular monitoring identifying new locations where the parasite has infected stocks, entire stocks and farms have been known to be removed (Ministry for Primary Industries, 2021). Effective engagement with the public was also deemed important to increase the awareness of biosecurity and transmission pathways.

Regular monitoring of oyster stocks would be needed to detect early presence of *Bonamia* in order for management to be most effective.

3.5.2. Habitat restoration and enhancement

Reseeding and translocating shellfish

Background

The restoration of bivalves through reseeding and translocation, particularly of native oysters, has become increasingly popular in recent years and in Europe, restoration projects have increased by 4 times over the past 3 years (Lee *et al*., 2020). In line with increasing initiatives to restore native oyster populations, the European Native Oyster Habitat Restoration Handbook was recently published for the UK and Ireland with the aims to provide guidance on the restoration and conservation of native oysters and their habitats (Preston et al., 2020). Mapping has also highlighted areas in the UK where opportunities for native oyster and horse mussel bed restoration may exist (Armstrong *et al*., 2021a). Restoration has the potential to increase the contribution shellfish beds have towards storage and sequestration of carbon.

Potential management measures

Projects currently restoring native oysters include the NRW led project in Milford Haven, which has introduced shell material/clutch (to create a suitable habitat) and 25,000 juvenile oysters across historic oyster grounds and aquaculture reared juvenile oysters across two sites (NRW, 2021b). Furthermore, the UK Wild Oysters Project (a partnership between Zoological Society London, Blue Marine foundation and British Marine) has introduced 1,300 broodstock native oysters to the River Conwy, suspending them underneath marina pontoons (ZSL, 2021).

In the Dornoch Firth, Scotland, the Dornoch Environmental Enhancement Project (DEEP) began in 2018 to restore native oyster reefs (*Ostrea edulis*) which were fished to extinction over 100 years. Approximately 20,000 native oysters were laid on shell material with the aim for the reefs to become self-sufficient and sustain 4 million oysters in a 40 ha area (BBC, 2018).

As part of the ENORI, native oyster spat are being relayed in the 200 ha no-take zone (called the Blackwater Conservation box) using shell material and gravel. In addition, 25,000 broodstock oysters were translocated to facilitate recruitment and improve seabed substrate.

Horse mussel (*Modiolus modiolus*) restoration has been attempted in the UK. A study was undertaken in 2010 in Strangford Lough, Northern Ireland, to investigate the success of translocation as a strategy for restoration (Roberts *et al*., 2011). The translocation of horse mussels involved the formation of an artificial reef with 10 tonnes of weathered scallop shells and seeding it with 6,000 adult horse mussels. It was found that translocation led to fast clumping of horse mussels to substrata (within 6 months) with high survival rates. These clumps also encouraged the natural recruitment of juvenile horse mussels. Translocation onto artificial reefs was therefore deemed likely to enhance recovery and natural recruitment of horse mussels. The artificial reef was also observed to host other mobile and sessile species such as fish, crustaceans, sponges, sea urchins and starfish. It was acknowledged, however, that consideration is needed when planning such projects to ensure sufficient quantities of mussels are translocated to increase chances of success (Roberts *et al*., 2011). With regard to Stranford Lough, a 2014 study determined that the restoration sites which were created in 2010 had in fact failed, and no obvious M. modiolus reef remained at the site four years on (Geraldi *et al*., 2014). Consequently, and also due to concerns over impacts on the donor site, the Northern Irish authorities decided against upscaling earlier translocation trials and to instead focus on protection (see previous section).

Restoration projects are in fact frequently unsuccessful, particularly where existing pressures are not effectively managed, or the environmental condition of an area are inappropriate. In 1997, an oyster restoration project in Strangford Lough, Northern Ireland, was undertaken in collaboration with the local fishing community (Kennedy and Roberts, 2001, Laing *et al*., 2005) whereby cultch, seeds and adult oysters were translocated to nine new sites. The oyster population increased from 100,000 individuals in 1998 to 1.2 million individuals in 2003. However, stock levels were depleted due to unregulated harvesting and infestation by the *Bonamia ostreae* parasite, leading to a decline of over 50% of individuals by 2005 (Smyth *et al*., 2009).

In 2010, the Chichester Harbour Oyster Partnership Initiative relayed 2,298 kg of broodstock native oysters on the seabed. Two years after relaying the oysters, high mortality of the oysters was reported. It was concluded that the environmental conditions at the seabed might have negatively affected oyster physiology, reducing growth and leading to increased mortality (Eagling, 2012).

Active restoration projects have the potential to increase shellfish abundance and in turn enhance the contribution bivalve beds make towards blue carbon. For these restoration schemes to be successful, potential issues or risks should be managed and regularly monitored, particularly in the early stages when resilience to environmental change could be lower.

Restoration projects for bivalves are costly. The project for oyster restoration in the Dornoch Firth required a total investment of £6.4 million to restore 40 ha of native oyster reefs. The sourcing of native oysters and setting up of shellfish supply chain cost approximately £1.4m. Overall unit costs for the Durnoch Firth scheme are around £160,000 per hectare (Armstrong *et al*., 2021a). In Australia, Preston *et al*. (2020) reported that 20 ha of Australian native oysters were restored in 2015, at a cost of £1.9 million (£95,000 per hectare). In a review of 23 projects, Bayraktarov (2016) calculated average per-hectare costs of between £28,000 and £329,000 for oyster bed restoration (2010 US dollar costs converted to pounds Sterling and 2020 prices).

3.5.3. Potential management in Welsh SACs

Based on the known pressures which have the potential to affect shellfish beds and associated blue carbon storage and sequestration in Wales, potential management measures for Welsh SAC are listed in **Table 12**, along with wider ecosystem benefits and feasibility of implementation.

Table 12. Blue carbon management actions for shellfish beds in Welsh SACs, the wider ecosystem benefits, feasibility of management approach to manage shellfish beds in Welsh SACs along with potential SACs where management could be implemented.

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Improve water quality	Improved water quality; increased biodiversity; establish potential nursery grounds	Medium. The source of the pollution must first be identified then management could enforce regulations or provide incentives to reduce sewage outflows and eutrophication.	Multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau
Reduce fishery activities	Habitat resilience; increased biodiversity	Medium. Fishing activities can be managed within SACs; however, it is often most effective when stakeholders are engaged and compliance monitoring undertaken	Collaboration and engagement; Multiple benefits	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau
Manage invasive non-native species	Reduce competition with native species; reduce smothering effects on native species	Low. Biosecurity most effective approach, management action is often ineffective once species are established.	Multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol
Manage / investigate pathogens and disease	Improve species abundance; Habitat resilience	Low. It is difficult to eradicate diseases; however, biosecurity protocols have been	Multiple benefits; Preventative action	Pembrokeshire Marine / Sir Benfro Forol

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
		successfully adopted to reduce the spread to other areas.		
Replanting for restoration	Habitat provision; Seabed stabilization; Increased species biodiversity; Improved water quality;	High. Replanting or reseeding attempts have been largely successful elsewhere. However, existing issues or risks need to be managed to ensure success.	Scale; multiple benefits; long-term; building resilience	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau

3.6. Sediment habitats

Sand, mud, and gravel sediments are known to contain large stores of organic and inorganic carbon. Carbon may be sequestered as precipitated carbonates or as particulate organic matter which has sunk to the seabed and is stored via biogeochemical processes. It is believed that organic carbon is sequestered into the seabed where it can remain for decades to centuries. Evidence of the impacts of pressures and the effect of management for protecting sedimentary carbon stores and sequestration are currently sparse. A number of projects have begun to focus on sedimentary habitats (for example work by Cefas as part of their Integrated Seabed Understanding Programme and Natural Capital Ecosystem Assessment). Attention is particularly turning towards physical disturbance, such as from bottom trawling, and how these activities may impact carbon stores alongside biodiversity.

Two main sedimentary habitats are listed as Annex I features within Welsh SACs. This includes ‘mudflats and sandflats not covered by seawater at low tide’ and ‘sandbanks which are slightly covered by seawater all the time’. Both of these habitats, along with other sediment areas, are major components of the Annex I features ‘estuaries’ and ‘large shallow inlets and bays’. Notable sandbanks in Wales include Helwick Banks in Carmarthen Bay and Estuaries SAC and Devil’s Ridge, Bastram Shoal and areas south of Tremadog Bay in Lleyn Peninsula and the Sarnau SAC. At Tremadog Bay, the seabed consists of a mosaic of different sediment types which support a diverse community of fauna and flora, designated under the large shallow inlets and bays feature. Mixed muddy sediments are also a habitat of principal importance in Wales under Section 7 of the Environment (Wales) Act 2016. The SACs and features which are designated for the protection of sediment habitats are listed in Table 13 along with the condition and known pressures which have the potential to impact condition.

Table 13. SACs designated for Annex I sediment habitat features along with the condition features and pressures currently known to or have the potential to impact condition.

SAC	Annex I feature protecting sediment habitats	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Cardigan Bay / Bae Ceredigion	Sandbanks	Unfavourable	Water quality
Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd	Estuaries	Unfavourable	Water quality
Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd	Large shallow inlets and bays	Unfavourable	Pollution

SAC	Annex I feature protecting sediment habitats	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd	Mudflats and sandflats	Unfavourable	Water quality
Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd	Sandbanks	Unfavourable	Water quality
Dee Estuary / Aber Dyfrdwy (Wales)	Estuaries	Unfavourable	Water quality
Dee Estuary / Aber Dyfrdwy (Wales)	Mudflats and sandflats	Favourable	N/A
Glannau Mon: Cors heli / Anglesey Coast: Saltmarsh	Estuaries	Favourable	N/A
Glannau Mon: Cors heli / Anglesey Coast: Saltmarsh	Mudflats and sandflats	Favourable	N/A
Y Fenai a Bae Conwy / Menai Strait and Conwy Bay	Large shallow inlets and bays	Unfavourable	Water quality
Y Fenai a Bae Conwy / Menai Strait and Conwy Bay	Mudflats and sandflats	Favourable	N/A
Y Fenai a Bae Conwy / Menai	Sandbanks	Favourable	N/A

SAC	Annex I feature protecting sediment habitats	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Strait and Conwy Bay			
Pembrokeshire Marine / Sir Benfro Forol (Native oysters)	Estuaries	Unfavourable	Water quality
Pembrokeshire Marine / Sir Benfro Forol (Native oysters)	Large shallow inlets and bays	Unfavourable	Water quality; bait digging; infrastructure development; INNS; Fishing (trawling)
Pembrokeshire Marine / Sir Benfro Forol (Native oysters)	Mudflats and sandflats	Unfavourable	Water quality; Bait digging; Mooring and anchoring
Pembrokeshire Marine / Sir Benfro Forol (Native oysters)	Sandbanks	Unfavourable	Water quality
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau (Horse mussels)	Mudflats and sandflats	Unfavourable	Water quality; Infrastructure and development; bait digging; Vehicle use
Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau (Horse mussels)	Sandbanks	Unfavourable	Decline in infaunal species
Severn Estuary / Môr Hafren	Estuaries	Unfavourable	Water quality
Severn Estuary / Môr Hafren	Mudflats and sandflats	Unfavourable	Water quality; coastal squeeze

SAC	Annex I feature protecting sediment habitats	Indicative assessment condition	Pressures with the potential to impact the condition of the feature
Severn Estuary / Môr Hafren	Sandbanks	Favourable	N/A

Where available, potential measures for managing the impacts of general disturbance of sediment habitats on carbon stock are detailed. This includes:

- Management of potential pressures;
  - Water quality;
  - Fishing; and
  - Access and recreation.

3.6.1. Management of potential pressures

Water quality

Background

There is limited literature on the effects of water quality on the carbon storage and sequestration of marine sediments, such as mudflats and sand flats or sandbanks. A study by Peterson and Melillo (1985) suggested that eutrophication leads to an increase in primary productivity from algal blooms and as a result can increase organic carbon reaching the sediments and subsequently being buried. In the coastal regions of the southern Baltic Sea, Meyer-Reil and Köster (2000) found that, with increasing eutrophication, concentrations of organic carbon in the sediments increased. Increasing carbon concentrations were reflected by increases in microbial biomass and decomposition potential. Similar results have been seen in lakes where organic carbon burial is higher in those which are impacted by eutrophication (Fiskal *et al*., 2019).

Potential management measures

Whilst changes in water quality could lead to higher burial rates of carbon in sediments, more research is needed into carbon sequestration under different eutrophication scenarios, along with a measure of the carbon uptake and release. Water quality in coastal ecosystems is recognised as having a negative impact on a range of habitats, including key blue carbon habitats such as saltmarshes and seagrasses which store and sequester large volumes of carbon (see Sections 3.1 and 3.2). Equally, changes in water quality can alter benthic fauna community structure and biodiversity which could act against the conservation objectives of MPAs.

Fishing

Background

It has recently been suggested that long-term carbon burial is threatened by processes that stir up sediment, particularly in the top few millimetres of seabed. This includes activities such as dredging and trawling which cause surface and subsurface disturbance of the sediments. However, the long-term effects of this disturbance on carbon storage are poorly understood. Some recent studies suggest that carbon could be lost as result of bottom trawling. For example, De Borger *et al*. (2021) suggested that fishing gear which disturbs the top layers of sediment can result in a loss of organic carbon and lead to release of carbon dioxide. Paradis *et al*. (2021) found that in comparison to untrawled areas, the continuous erosion and sediment mixing in trawling grounds led to coarser reworked sediments impoverished in organic carbon (30% loss). After closing areas to trawling, the impacts persisted after two months due to the slow nature of sequestration. Similarly, a study on the effect of bottom trawling on deep-sea sediments found that trawled sites were also impoverished in organic carbon (Martin *et al*., 2014). Palanques *et al*. (2014) showed, however, that bottom trawling led to an increase in carbon in the surface sediments in continental shelf sediments.

Potential management measures

Overall, more research is needed to understand the impact bottom fishing on sediment carbon stocks prior to appropriate management measures being identified and implemented. If it is found that such activities negatively impact carbon storage and sequestration, closures of area to bottom fishing activities could be considered to protect these habitats.

Access and recreation

Background

Much like the fishing activities, activities such as mooring and anchoring, bait digging, trampling or vehicle access can also cause disturbance to sedimentary habitats. It is largely unknown how these activities may impact on the carbon storage and sequestration potential of habitats such as mudflats, sand flats and sandbanks.

Potential management measures

Measures such as area closures or eco-moorings could be used to limit the effect of these activities on sedimentary habitats. However, further research is needed to understand the effects of access and recreation activities on sedimentary carbon storage and sequestration prior to identifying appropriate management measures.

3.6.2. Potential management in Welsh SACs

Based on the known pressures which have the potential to affect sedimentary habitats and associated blue carbon storage and sequestration in Wales, potential management measures for Welsh SAC are listed in in Table 14 along with wider ecosystem benefits and feasibility of implementation. It is considered that more research is needed to assess the impact of disturbance on these sediment habitats and their carbon stocks before management measures can be implemented.

Table 14. Blue carbon management for sediment habitats in Welsh SACs, the wider ecosystem benefits, feasibility of management approach to manage sediment habitats in Welsh SACs along with potential SACs where management could be implemented.

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Improve water quality	Improved water quality; Increased biodiversity; establish potential nursery grounds	Medium. The source of the pollution must first be identified then management could enforce regulations or provide incentives to reduce sewage outflows and eutrophication.	Multiple benefits; preventative action	Cardigan Bay / Bae Ceredigion Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd Dee Estuary / Aber Dyfrdwy (Wales) Glannau Mon: Cors heli / Anglesey Coast: Saltmarsh Y Fenai a Bae Conwy / Menai Strait and Conwy Bay Pembrokeshire Marine / Sir Benfro Forol (Native oysters) Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau (Horse mussels) Severn Estuary / Môr Hafren

Potential management action to protect and enhance blue carbon	Wider ecosystem benefits of management	Feasibility of management approach	Principles of SMNR	Potential SACs where management could be implemented
Reduce fishery activities	Habitat resilience; Increased biodiversity	Medium. Fishing activities can be managed within SACs; however, it is often most effective when stakeholders are engaged and compliance monitoring undertaken	Collaboration and engagement; Multiple benefits	Pembrokeshire Marine / Sir Benfro Forol
Reduce disturbance from moorings and anchors / access and recreation	Increased species diversity; Reduced disturbance on other species	High. UK-based evidence of eco-mooring adoption and protection of sedimentary habitats. Measures may need to be legislative (as well as voluntary) but monitoring of compliance would be recommended. Physical barriers and clear signage could also be used.	Collaboration and engagement; public participation; multiple benefits; preventative action	Pembrokeshire Marine / Sir Benfro Forol Pen Llŷn a'r Sarnau / Lleyn Peninsula and the Sarnau

4. Policy and regulatory pathways for managing blue carbon in SACs

This review covers examples of the policy and regulatory pathways for managing blue carbon in Welsh SACs. Firstly, this includes reviewing the potential inclusion of blue carbon within marine policy and planning. The implementation of management measures in SACs in terms of non-licensable and licensable activities is then described before reviewing the potential inclusion of blue carbon management within the conservation objectives of SACs. Lastly, wider approaches which could be used to protect blue carbon habitats are identified.

4.1. Marine policy and planning

A range of national regulatory frameworks recognise the importance of mitigating against climate change and safeguarding or restoring carbon stores. In Wales, these include, but are not limited to:

- Environment (Wales) Act 2016;
- Future Wales – the 2021 National Plan (National Development Framework);
- Natural Recovery Action Plan for Wales;
- Natural Resources Policy (NRP);
- Planning Policy Wales (PPW);
- Well-being of Future Generations (Wales) Act 2015; and
- Welsh National Marine Plan (WNMP).

One such example is under Objective 8 of the WNMP (2019) which contains a commitment to 'improve the understanding and enable action supporting climate change adaptation and mitigation' to 'ensure a strong, healthy and just society'. Support from these policies should mean that the mechanisms for protecting and enhancing blue carbon are in place.

The WNMP also sets out climate change policies for development in the marine environment. For example, Policy SOC_10 requires any proposals to demonstrate how they:

- Avoid the emission of greenhouse gases; and / or
- Minimise greenhouse gases where they cannot be avoided; and / or
- Mitigate them where they cannot be minimised.

The policy details that emissions directly and indirectly related to the development or activity should be considered within the proposals. The emissions considered are generally associated with construction and operation. Proposals which plan to overlap blue carbon habitats could be assessed for potential blue carbon emissions and future losses to sequestration potential.

Under policy SOC_11 in the WNMP, proposals are encouraged to include measures contributing towards climate change mitigation and adaptation. Under this policy, proposals which avoid impacts on blue carbon habitats or offset carbon emissions through restoration could be encouraged.

4.2. Implementation of management in SACs

4.2.1. Non licensable activities

Where a specific licence or permission is not required, management measures can be voluntary or statutory in nature. Often, measures which aim to regulate unlicensed activities, such as area closures or gear restrictions, are implemented into law to strengthen compliance and enforcement. Byelaws and orders are often used as a means to implement management measures to protect locations from damage or deterioration.

Byelaws are local laws made by statutory bodies under the Local Government Byelaws (Wales) Act 2012. Statutory bodies with powers to implement a byelaw include local councils, National Park Authorities and NRW. Byelaws can be implemented for:

- The good rule and government of the whole or any part of an area; and
- The prevention and suppression of nuisances in an area.

Byelaws cannot be implemented as a mechanism to meet the conservation objectives of an SAC. Instead, orders can be implemented under Regulation 40 of the Habitats Regulations for the protection of European Marine Sites (SACs and SPAs). Special Nature Conservation Orders (SNCOs) in Wales are issued by the Secretary of State or Welsh Ministers, based on recommendations from Natural England or NRW, respectively. SNCOs can be requested if monitoring shows a site is being damaged or is at risk to being damaged. However, an SNCO can only be used where:

- The site cannot be protected by other regulations - for example planning or byelaws; and
- Other measures have not worked or are not possible - for example voluntary agreements.

4.2.2. Licensable activities

Development has the potential to lead to the loss of blue carbon habitats, and damage to blue carbon habitats is recognised as a potential source of carbon emissions. In addition, these habitats are known to mitigate against climate change and their loss as a result of development has the potential to reduce the carbon uptake from the atmosphere.

When determining marine licence or planning applications (or equivalent permissions), decision makers need to be satisfied that there will be no significant adverse effects arising from a proposed project. This should serve to protect blue carbon habitats through a hierarchy of avoidance of adverse impacts, mitigation and compensation.

In the specific instances where an Environmental Impact Assessment (EIA) is required in support of applications, climate change needs to be adequately considered. The 2017 EIA Regulations 2017 (Schedule 4) require that an EIA provides:

“A description of the likely significant effects of the development on the environment resulting from … (f) the impact of the project on climate (for example the nature and magnitude of greenhouse gas emissions) and the vulnerability of the project to climate change”.

A Habitats Regulations Assessment (HRA) is required for any plan or project which has the potential to adversely affect the features of a European/Ramsar Site. Where adverse effects are predicted, and cannot be avoided or mitigated, compensation is required to be provided (subject to a series of stringent tests being met). This should therefore help to protect blue carbon habitats in Welsh SACs.

Similarly, a Water Framework Directive (WFD) compliance assessment is required to ensure a proposed project complies with the objectives of the WFD which again serves to protect such habitats.

These assessments present an opportunity for the potential impacts of proposed plans on blue carbon habitats to be assessed in terms of the damage or loss of carbon sinks and potential increases in blue carbon emissions.

4.3. Conservation of Habitats and Species Regulation 2017

The focus for the identification, designation and management of SACs has been on the protection of key fauna and flora. SACs have been designated under the Conservation of Habitats and Species Regulations 2017 (as amended); this relies on the identification of habitats specified as Annex I or species specified as Annex II in the Habitats Directive. Once designated, conservation advice is produced under Regulation 37 (3) of the Habitats Regulations which states that:

“As soon as possible after a site becomes a European marine site, the appropriate nature conservation body must advise other relevant authorities as to—

(a) the conservation objectives for that site; and

(b) any operations which may cause deterioration of natural habitats or the habitats of species, or disturbance of species, for which the site has been designated.”

These conservation advice packages for European Marine Sites detail the conservation objectives and operations advice along with the legal context to assist relevant authorities and other decision-makers in determining whether proposed activities may affect the protected features of a European Site.

The Regulations require that measures are taken to maintain or restore habitats and species to favourable condition. The conservation objectives for different habitat features are explained in terms of the various elements, which include:

- Range - including distribution and extent;
- Structure and function - including geology, sedimentology, geomorphology, hydrography and meteorology, water and sediment chemistry and biological interactions;

- Typical species - including species richness/evenness, population dynamics and range as defined for species features; and
- Natural processes.

In the marine environment, many of the features for which SACs are already designated are key blue carbon sinks, including saltmarshes, sedimentary habitats and a range of biogenic reefs. The protection of these habitats from damage could potentially promote carbon capture and storage and ensure that carbon stores are not lost (Laffoley *et al*., 2019). As it stands, recognition specifically for the protection of blue carbon habitats is not included within Regulation 37 and the conservation objectives for European Marine Sites.

As the main attributes of the Annex I features are protected by a site's conservation objectives, more emphasis could be included on the importance of blue carbon habitats in each protected feature within the elements listed above, such as structure and function or natural processes This would then allow blue carbon to form part of the conservation objectives for a site, with the aim of maintaining/restoring these features to favourable condition. Once blue carbon habitats are emphasised in the conservation objectives for a site, the advice for operations could then clearly highlight operations which may cause deterioration or disturbance to blue carbon habitats.

4.4. Wider approaches for protecting blue carbon habitats

A range of additional approaches currently exist or have been identified for protecting blue carbon habitats. These include:

- Implementing blue carbon into the current frameworks for designating marine protected areas;
- Developing new plans specifically for the protection and restoration of blue carbon; and
- Accounting for blue carbon within carbon emission budgets.

In Scotland, 'Nature Conservation Marine Protected Areas' (NCMPAs) are a type of protected area that can be designated in Scottish territorial and offshore waters. These NCMPAs are designated under the Marine (Scotland) Act 2010 which outlines in Section 68 that:

"In considering whether to designate an area, the Scottish Ministers may have regard to the extent to which doing so will contribute to the mitigation of climate change."

This has provided Scottish Ministers with the power to protect blue carbon habitats, including those which are not protected as Annex I features, on the basis that disturbance has the potential to result in carbon dioxide emissions and that protection can enhance carbon sequestration. The protection of blue carbon habitats has also been reinforced in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, which set targets for emissions reductions. The Act highlights the role of MPAs in the protection of carbon stores and their consideration in subsequent climate change plans, stating under Section 35(15) that:

“The [Climate Change] plan must also set out the Scottish Ministers’ proposals and policies regarding the consideration of the potential for the capture and long term storage of carbon when designating marine protected areas under section 67 of the Marine (Scotland) Act 2010”.

As of yet, no NCMPAs in Scotland have been designated based on their contribution to climate change mitigation (Shafiee, 2021). This is potentially due to the lack of overall evidence on whether such management will lead to the protection or enhancement of blue carbon. Designation of marine areas as ‘NCMPA’ are specific to Scotland and do not cover England or Wales.

The Marine Conservation Society (MCS) recently outlined policy recommendations for blue carbon in Wales, in order for Wales to meet ambitious targets to cut carbon emission by 95% by 2050 (MCS, 2020). One recommendation focussed on the development and implementation of a national Blue Carbon Recovery Plan. The aim of the plan would be to restore key blue carbon habitats through inland migration and expansion of habitats, including an increase in managed realignment schemes for flood defence. As part of this proposed plan, ‘Blue Carbon Zones’ could be designated as areas recognised for their carbon storage and / or sequestration potential and would then be protected from activities which disturb the habitats. The Plan could potentially be funded through current carbon offsetting programmes (MCS, 2020).

The Environment (Wales) Act 2016 outlines in Section 39 that Welsh Government must set out proposals and policies for meeting national carbon budgets. Fully accounting for blue carbon within such carbon budgets, as a nature-based solution to offset carbon emissions, has also been acknowledged as a potential incentive for the protection and enhancement of carbon stocks and habitats which sequester carbon.

5. Conclusions and recommendations

The literature review undertaken in this report has identified a range of management options which have the potential to protect and enhance blue carbon habitats in Welsh SACs. These measures cover a wide range of options for managing potential pressures and habitat restoration and enhancement approaches. The protection of habitats through the management of known pressures, such as reduced water quality, access and recreation and fishing, was found to be the most common management tool used with the potential to enhance blue carbon stocks. Habitat creation and restoration schemes have also been undertaken for a range of blue carbon habitats, particularly for saltmarsh, seagrass and shellfish beds. However, the success of these projects relies on careful planning (including assessments, consents and timing of project) and management of pressures potentially impacting a site such as pollution. Furthermore, for several of the habitats, UK experience with active restoration is still in its infancy, and successful restoration not guaranteed.

Potential policy and regulatory pathways for management of blue carbon habitats within SACs have been highlighted. This included the consideration of blue carbon for achieving favourable condition within the Conservation Objectives as part of Regulation 37 under the Conservation of Habitats and Species Regulations 2017. In addition, regulatory frameworks supporting marine developments should acknowledge that blue carbon can be used as a tool to mitigate against climate change, and that damage or loss of blue carbon sinks releases carbon emissions. This should be captured within the consenting and decision-making processes associated with such projects.

The potential value associated with the implementation of such measures is based on the assumption that improving the condition and extent of Annex I features has the potential to enhance carbon storage and sequestration. However, more evidence is needed on the actual relationship between habitat condition and the carbon storage and sequestration potential of such habitats. In addition, it is important to gain a greater understanding of the magnitude of the reduction in carbon storage and sequestration that is caused by the risks and issues that have been identified. It is likely that such information would greatly facilitate the justification and implementation of management measures to specifically protect blue carbon habitats. Similarly, investigations on carbon storage and sequestration before and after management measures are implemented are rare in the literature. It is suggested that before and after studies are undertaken to assess the effectiveness of management measures in specifically enhancing blue carbon potential. Such investigations would greatly increase understanding on the usefulness of different management options, along with highlighting potential ways in which to improve measures.

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7. Appendix A

Data has been provided to NRW which reviews management measures which have the potential to protect and enhance blue carbon in Wales. The data was provided, in Microsoft Excel format, via email on 11 February 2022 and is available on request as R3791_BlueCarbonManagementEvidenceDatabase_11Feb22.xls.