Blue Carbon Restoration in Northern Ireland – Feasibility Study

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Saltmarsh ©Paul Corbett

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Summary

What is blue carbon?

- Blue carbon refers to carbon captured (sequestered) and stored in the marine and coastal environment. In Northern Ireland, living (biological) marine and coastal habitats (such as saltmarshes, seagrasses, kelp beds, and biogenic reefs) and geological sedimentary stores (such as seafloor and sea lough sediments) store carbon.
- The main threats to blue carbon habitats are physical disturbances, climate change, and land-use and land management changes. If in a poor state of health or unprotected from threats, blue carbon habitats may release their stored carbon, becoming a future source of carbon emissions.
- Management of blue carbon habitats is becoming increasingly crucial as part of our response to the Climate Emergency, with three approaches core to this response: habitat protection, restoration and creation.

Quantifying Northern Ireland's coastal blue carbon habitats

- The estimated current extent of coastal blue carbon habitats (saltmarsh, seagrass meadows, kelp forests, and shellfish beds) in Northern Ireland (NI) is 658 km^2, with 371 km^2 occurring within the inshore MPA network.
- The carbon sequestration rate of these habitats is estimated to be 31,595 t C per year.
- The carbon sequestration rate of the inshore MPA network is estimated to be 14,707 t C per year.
- There is potential to triple the blue carbon value of the MPA network to 52,958 (t C yr^{-1}) through effective protection and habitat restoration/creation within the MPA network.
- The sea loughs are important blue carbon areas as they contained a high proportion of estimated current extent (occupied habitat) and suitable habitat (unoccupied habitat) for many of the species.

The blue carbon estimates provided in this report are based on limited knowledge and understanding of the natural ability of these habitats to capture and sequester carbon at a local scale. Many challenges need to be addressed in order to more accurately estimate the blue carbon within individual habitats.

Partnership working

Ulster Wildlife hosted a virtual workshop on the 17th February 2021 and was attended by 84 representatives from NGOs, academic institutions, government agencies and local councils. It was evident from the workshop that partnership working is essential for habitat restoration programmes in order to access the expertise, funding and resources required for success. This workshop forged the beginnings of potential partnerships for future blue carbon habitat restoration work in Northern Ireland.

Priority areas for future work include:

Evidence:

- Develop a baseline inventory of all blue carbon habitats in Northern Ireland: their extent, with local measurement of carbon sequestration rates (CSRs) and estimated total carbon storage by habitat, including understanding how the condition of habitat affects CSR.
- Ground-truth current estimated extent and habitat suitability areas in this blue carbon report and identify habitat condition and any notable local pressures at each site.

- Investigate the likely response of blue carbon habitats to climate change, especially those coastal habitats that are the current focus for practical restoration.
- Understand and evaluate the co-benefits of restoration, such as biodiversity gains, enhancement of other ecosystem services such as flood protection, water quality improvement, and community buy-in/ownership.

Policy & Management:

- Raise awareness of the potential for blue carbon to contribute to Nationally Determined Contributions to the UK's greenhouse gas inventory under the Paris Agreement via engagement with policy-makers and the Climate Change Committee.
- Raise public and policy-makers' awareness of blue carbon as a nature-based solution to climate change, including updating the Northern Ireland Marine Plan to strengthen commitment to this approach.
- Develop a cross-cutting blue carbon strategy that would underpin action to protect, restore, recreate and monitor blue carbon habitats, with priority given to protection and restoration of existing habitats.
- Incorporate the carbon sequestration value of blue carbon habitats into the Marine Protected Area designation and management process levering existing policy commitments for this purpose and making MPAs 'climate smart'.

Pilot Projects

Identify pilot projects for coastal blue carbon restoration through

- Further development of the blue carbon restoration feasibility GIS and identification of habitat condition and local carbon sequestration rates, followed by:
- Prioritisation of habitats based on their carbon sequestration and storage potential and practicality of restoration actions (exploring the options of co-restoration of habitats).

The development of partnerships, securing funding and building capacity locally for blue carbon restoration with flagship local projects will inspire further habitat restoration efforts and demonstrate viability, while also monitoring the co-benefits of habitat restoration such as biodiversity value and erosion protection.

Research Briefing

Introduction

This research briefing details coastal habitats that contain blue carbon (see table 1) where they are located and the various threats they face. It describes the links between blue carbon habitats and climate change, specifically in terms of the ability of these habitats to sequester and store carbon. The briefing also highlights blue carbon research and conservation programs ongoing in the UK, as well as various policies relevant to blue carbon.

Northern Ireland's inshore region contains seagrass, saltmarsh, shellfish and seaweed habitats. Analysis presented in this briefing indicates that approximately 658 km^2 of coastal blue carbon habitat is located within Northern Ireland's inshore area. Blue carbon is therefore an important consideration for climate change mitigation and adaption in the context of the climate emergency declared by the Northern Ireland Assembly on 3rd February 2020.

Table 1 Focus coastal blue carbon habitats and species in this study.

Seagrass species	Shellfish species	Kelp species	*Saltmarsh
Zostera marina	*Mytilus edulis*	*Saccharina lastissima*	
Zostera noltei	*Ostrea edulis*	*Laminaria digitata*	
		Laminaria hyperborea	

*Saltmarsh – based on the occurrence data provided, it was not possible to differentiate native saltmarsh and that containing invasive *Sporobolus anglicus* (formally *Spartina anglica*) in this research.

Blue Carbon and the role of coastal habitats

Blue carbon is high-density carbon that accumulates in oceans and coastal ecosystems as a result of their high productivity and sediment trapping ability.

Coastal habitats, predominantly vegetated habitats such as seagrasses and saltmarsh, have a disproportionate capacity to sequester carbon dioxide (CO_2) from the atmosphere and incorporate it into biomass, which ultimately becomes buried as organic matter within the sediments. Organic matter in sediment is exposed to a limited oxygen supply, especially in anoxic sediments, resulting in low degradation rates and a low rate of CO_2 release to the atmosphere. Carbon sequestered in marine habitats is partitioned as that associated with living material, termed 'above ground biomass' (photosynthetic leaves, animal tissue and shell) and 'below ground biomass' (roots, rhizomes) and the non-living material in the sediment. Many coastal habitats such as saltmarsh, seagrass and shellfish beds also act to trap sediment which provides a key mechanism in carbon sequestration.

Blue carbon may be viewed as a 'triple value' climate solution, simultaneously offering benefits in climate change mitigation, adaptation and resilience. As a climate action, protection and restoration of blue carbon ecosystems offers a high return on investment across a variety of human and natural impacts. Furthermore, many coastal blue carbon habitats provide a range of important co-benefits, or 'ecosystem services', such as being of high biodiversity value, as fish nursery grounds, by improving water quality (e.g. shellfish beds) and as coastal flood protection/erosion resilience. Such co-benefits become increasingly important as climate change exerts pressures on coastal areas.

Table 2 Blue carbon habitat in Northern Ireland's waters

Marine and coastal habitats:
Saltmarshes*
Intertidal macroalgae
Blue mussel (*Mytilus edulis*) reefs*
Seagrass beds*
Sediments- muds, gravels, sands*
Native/flat oyster (*Ostrea edulis**) reefs
Kelp forest
Horse mussel (*Modiolus modiolus*) beds*
Brittlestar beds*
Subcanopy algae
Maerl beds*
Sabellaria reefs*

Yellow = intertidal
Green = intertidal and subtidal
Blue = subtidal
*= existing priority habitats or species, or pMCZ component habitat

The blue carbon policy context in Northern Ireland

Management of blue carbon habitats is becoming increasingly crucial as part of our response to the Climate Emergency, with three approaches core to this response: habitat protection, restoration and creation.

DEFINITIONS

Restoration: the manipulation of the physical, chemical, or biological characteristics of a degraded site, with the goal of enhancing natural functions or species communities in an existing habitat.

Creation: the manipulation of the physical, chemical, or biological characteristics of a site to develop a habitat that did not previously exist.

Protection: an action to remove a threat to, or prevent the decline of the condition of a habitat or species.

(MMO, 2019)

Box 1 Definitions of habitat protection, restoration and creation

Many countries are already including blue carbon habitats within their Nationally Determined Contributions (NDCs) to the Paris Agreement greenhouse gas (GHG) inventory: this helps better understand the role these habitats have in carbon storage and sequestration and provides an opportunity for habitat restoration to increase carbon storage and potentially offset emissions, which will provide a Nature-Based Solution (NbS) that assists countries in achieving net zero emissions.

There are currently no policies in Northern Ireland to promote restoration of blue carbon habitats, in comparison to peatlands and forestry. This project and other ongoing initiatives are supporting the development of strategies encompassing blue carbon within NI policy.

Some Northern Irish blue carbon habitats are protected from threats, based on their contributions to our biodiversity, mainly in the form of marine protected areas (MPAs). For example, Waterfoot Marine Conservation Zone (MCZ) is a small embayment offshore from the east coast of County Antrim designated for seagrass beds (*Z. marina*). However, blue carbon habitats and species present within MPAs are not necessarily protected if they are not the features for which the site was designated. Furthermore, only 4.48% of NI's inshore MPA network is favourably managed, with potentially damaging activities such as anchoring of recreational boats and bottom-towed fishing gear activity still occurring within NI's inshore MPAs[1].

The DAERA Marine and Fisheries Division have stated that within the current policy framework it is possible to consider carbon storage in the marine environment when designating MPAs (but have not provided details of the mechanism). It is of note that the Scottish Climate Change Act (2019) requires Ministers to set proposal and policies in their Climate Change Plan that consider carbon storage in the marine environment when designating MPAs.

Threats to blue carbon habitats

The importance of blue carbon ecosystems in mediating atmospheric carbon dioxide and, hence, mitigation against climate change is now widely recognised, however, there is a long-term trend of coastal habitat loss and degradation through, for example, land claim, benthic fishing activities, alteration of sediment dynamics and eutrophication. For example, in the UK, it is estimated that seagrass loss amounts to between 84 and 92%[2]. If blue carbon ecosystems are in a poor state of health or unprotected from threats, they may release their stored carbon, becoming a future source of carbon emissions.

There is now an urgent need to manage threats to coastal blue carbon habitats, with an emphasis first on protecting existing areas of these habitats, then restoration and finally potential recreation of habitats. Across the UK, there have been widespread efforts to restore native oyster reefs (e.g. the Native Oyster Restoration Alliance (NORA), the Dornoch Environmental Enhancement Project (DEEP) and the Solent Oyster Restoration Project). Saltmarsh creation and restoration has been achieved through managed realignment programmes undertaken by the Environment Agency and, notably, ABPmer and the National Trust and Project Seagrass (Swansea University) has, for a number of years, carried out research into seagrass restoration techniques and seagrass habitat management.

Quantifying coastal blue carbon habitats in Northern Ireland

The estimated current extent of coastal blue carbon habitats in Northern Ireland is 658 km^2, with 371 km^2 occurring within NI's inshore MPA network. A high proportion of the extent of *Z. marina*, *Z. noltei*, saltmarsh, *M. edulis* and *O. edulis* occurs within the sea loughs. Both *L. digitata* and *L. hyperborea* are extensively distributed along the open coast. *S. latissima* appears to prefer more sheltered waters and occurs both along the open coastline and in the sea loughs. The estimated current extent of blue carbon habitats is presented in table 3. It is important to note that the extent

[1] A consultation on the development of fisheries management measures for Marine Protected Areas (MPAs) and establishment of Scallop enhancement sites in the Northern Ireland inshore region opened on 30 Nov 20 and closed 31 Mar 21. Ulster Wildlife submitted a response.

[2] Green, A. E., Unsworth, R. K., Chadwick, M. A., & Jones, P. J. (2021). Historical analysis exposes catastrophic seagrass loss for the United Kingdom. *Frontiers in Plant Science*, *12*, 261.

is based on presence only and should not be taken as a reflection on the condition of the sub-populations within patches.

Each species and habitat were attributed their 'Carbon Sequestration Rate' (CSR) to capture their value for facilitating carbon storage. The CRS values were obtained from the literature and can be found in Table 4. Collectively, Northern Ireland's saltmarsh, seagrass meadows, and shellfish beds, potentially sequester 31,595 t C per year.

Modelled suitable habitat highlights the areas with the appropriate environmental conditions for a specific species that aren't occupied by that species. As per the estimates of extent, a high proportion of the suitable habitat for *Z. marina*, *Z. noltei*, saltmarsh, *M. edulis* and *O. edulis* occurs within the sea loughs. The HS maps predict large amounts of suitable habitat subtidally but it is recognised that many subtidal areas cannot persist without sustained aquaculture practices. Suitable habitat for both *L. digitata* and *L. hyperborea* is extensively distributed along the open coast. The preference of *S. latissima* for sheltered waters places suitable habitat both along the open coastline (e.g. Ards Peninsula) and in all of the sea loughs. The high suitability extent of blue carbon habitats is presented in table 4. The reasons why suitable habitat remains uncolonised (or unrealised) may well be due to constraints on dispersal, biological factors (e.g. high predation, competition or disease pressures), or human pressures.

The analysis demonstrates that the blue carbon habitat within the Northern Irish inshore MPA network is potentially storing 14,707 t C yr^{-1}. However, only 4.48% of the inshore MPA network is favourably managed[3], and potentially damaging activities such as anchoring of recreational boats and benthic fishing still occur within these sites and are possibly impacting their carbon storage capacity. Effectively protecting current blue carbon extent and enhancing their blue carbon potential through the implementation of fit-for-purpose management plans and habitat restoration and/or creation within the MPA network, there is potential to at least triple the blue carbon value of the MPA network to 52,958 (t C yr^{-1}). The high suitability extent of blue carbon habitats is presented in table 4, and the blue carbon values are presented in table 5.

[3] https://www.daera-ni.gov.uk/sites/default/files/publications/daera/ni-environmental-statistics-report-2020_0.pdf

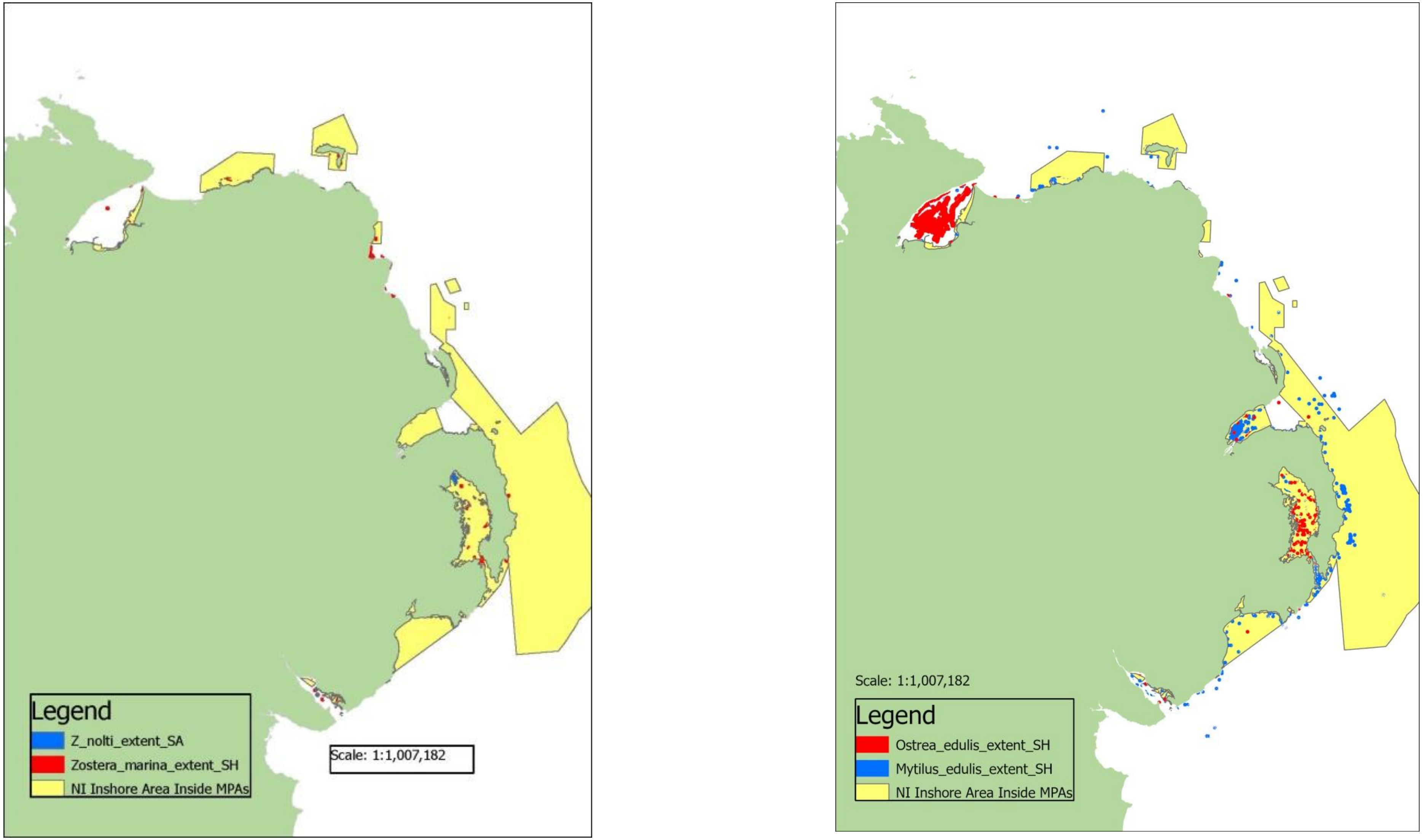


Figure 1 Estimated current extents of coastal blue carbon habitats in Northern Ireland (seagrass species on left, shellfish species on right)

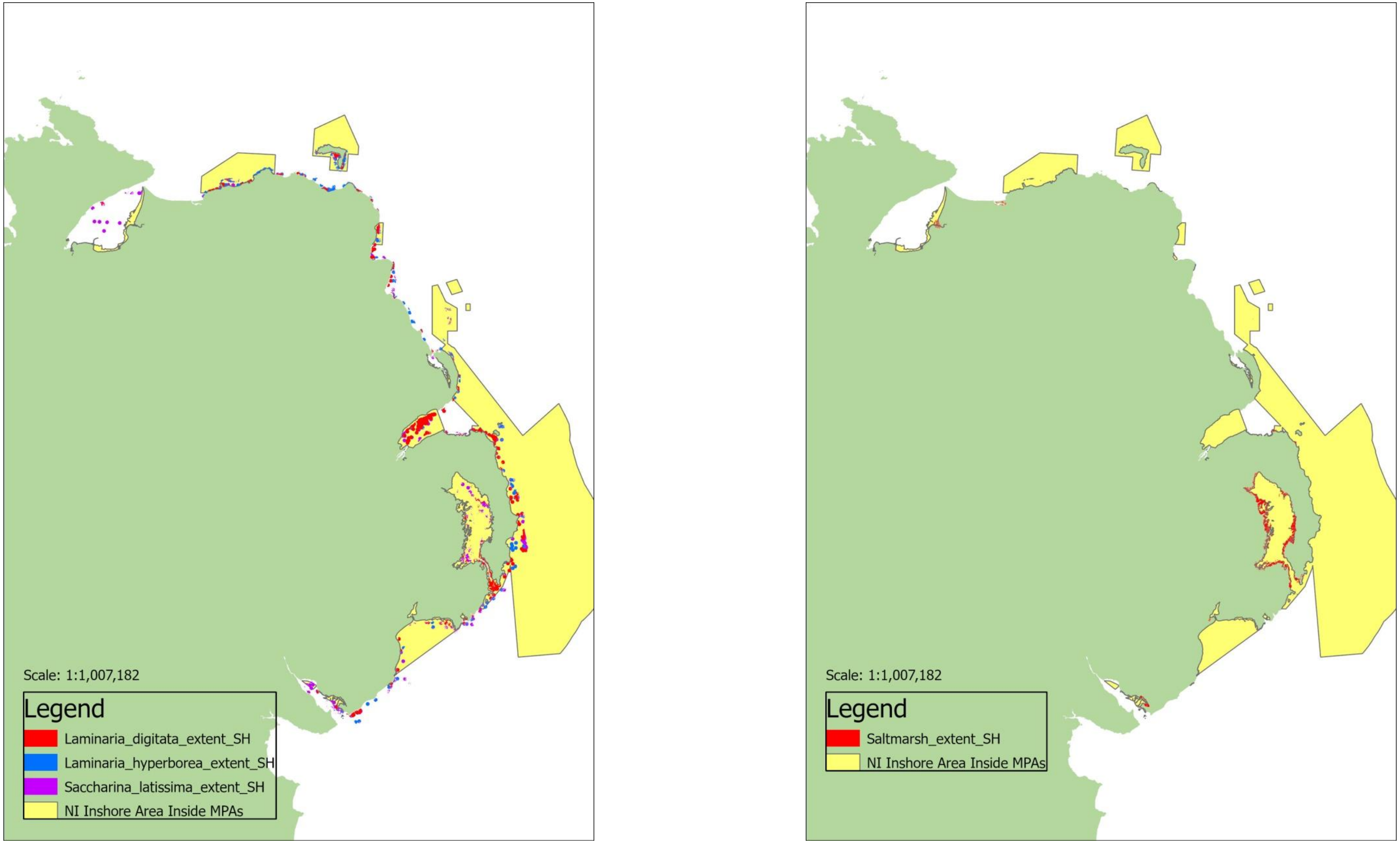
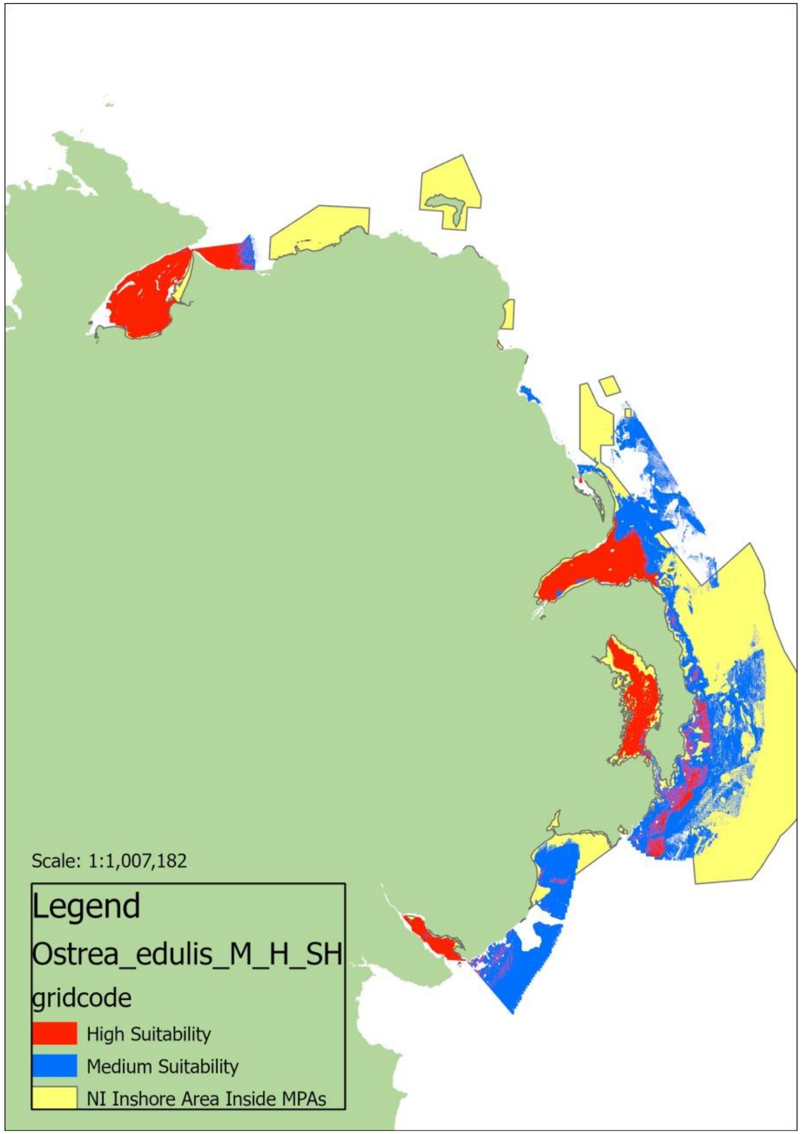


Figure 2 Estimated current extents of coastal blue carbon habitats in Northern Ireland (kelp species on left, saltmarsh on right)



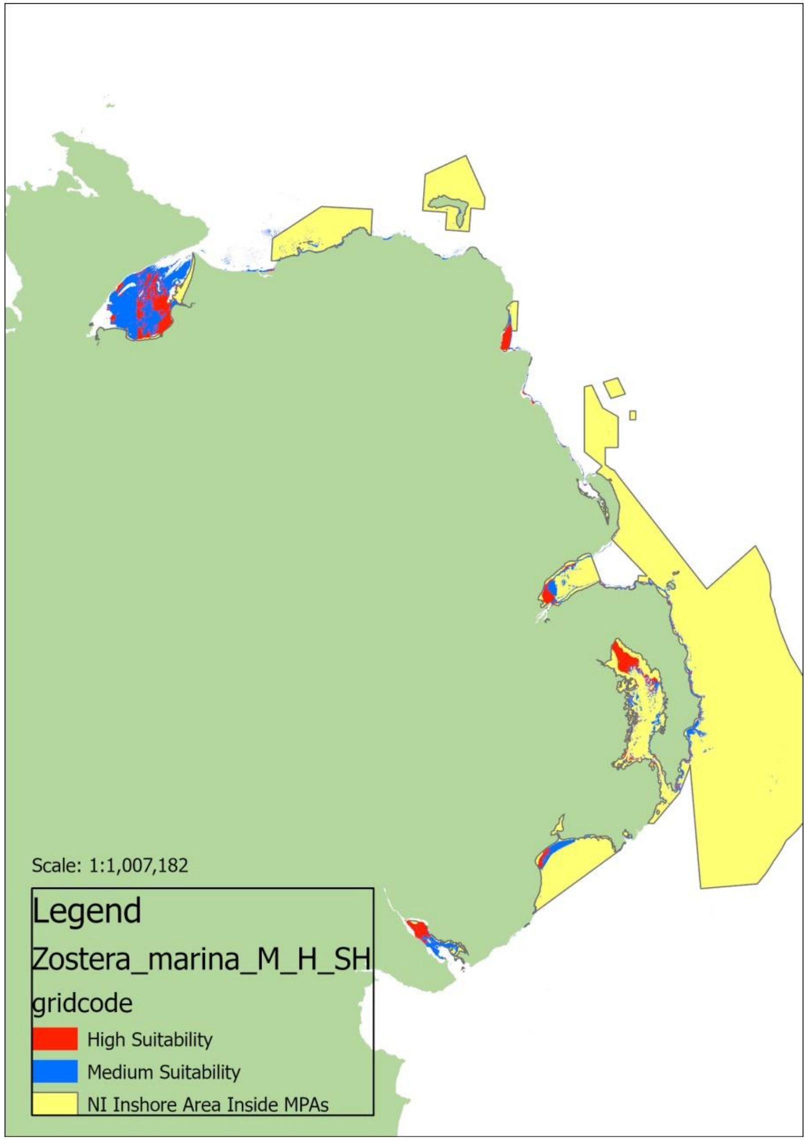


Figure 3 Estimated suitable area for *O. edulis* (left) and *Z. marina* (right). Suitable area habitat maps for the other species are included in the final report

Table 3 Extent and high suitability area for all habitats and species

Species or habitat	Extent area (km^2)	Extent area in MPA network (km^2)	High suitability area (km^2)	High suitability area within MPA network (km^2)
Laminaria hyperborea	82.2	55.1	97.0	70.8
Laminaria digitata	83.7	65.1	122.9	105.1
Ostrea edulis	167.9	41.0	486.3	211.7
Mytilus edulis	140.2	97.6	878.5	404.2
Saccharina latissima	136.0	92.8	290.4	168.8
Saltmarsh	31.1	8.5	13.7	3.2
Zostera marina	15.8	11.1	87.3	38.8
Zostera noltei	1.4	-	127.5	23.3

Table 4 Carbon sequestration rates per species or habitat

Species or habitat	Sequestration rate (g C m^2 yr)	References
Laminaria hyperborea	0	Observations from across the UK and considered suitable for use for Northern Irish populations. Values reported here are from the nearest station to Northern Ireland (west coast of Scotland).
Laminaria digitata	0	Observations from across the UK and considered suitable for use for Northern Irish populations. Values reported here are from the nearest station to Northern Ireland (west coast of Scotland).
Ostrea edulis	50	Values based on 75 ind/m^2, which is significantly greater than the natural density of *O. edulis*. The values reported here are considered an over-estimation of local rates
Mytilus edulis	81	Observations of mussels from Vrdngskar (Baltic). The reported value is a mean of several seasonal measurements and is considered suitable for use for Northern Irish populations.
Saccharina latissima	0	In situ observations from Rhode Island USA. The reported value s here are considered moderately suitable for Northern Irish populations.
Saltmarsh	266	Meta-data mean based on 174 reviews, 414 papers and 56 book chapters. The values report here are considered a suitable average for saltmarsh in Northern Ireland.
Zostera marina	226	The same values were used for a similar study in Scotland. The values reported here are considered to be moderately suitable for use with Northern Irish populations.

Table 5 The blue carbon value (i.e. sequestration rate multiplied by the area) of *O. edulis*, *M. edulis, Z. marina* and saltmarsh in the Northern Ireland inshore region.

Species or Habitat	Value of BC in NI inshore region (t C yr^{-1})	Value of BC in MPA network (t C yr^{-1})	*Potential value of BC in inshore region (t C yr^{-1})	*Potential value of BC in MPA network (t C yr^{-1})
Ostrea edulis	8395	2049	24315	10587
Mytilus edulis	11356	7906	71159	32744
Saltmarsh	8273	2253	3644	863
Zostera marina	3571	2500	19730	8764
Total	31595	14707	118848	52958

* Potential value of blue carbon is based on high suitability area values.

A precautionary approach should be taken when interpreting the maps produced by this study. It is important to note that it is difficult to model species and habitats that occur intertidally or in shallow subtidal habitats. Intertidal and high shore areas often fall between two stools i.e. they are not sufficiently addressed by terrestrial mapping and modelling products or marine products. As such, modelling can be hampered by missing or inaccurate predictor variables. Regardless of the challenges, spatial estimates of occupied and potential habitats are essential for habitat restoration and creation site selection. For example, the extent maps provide valuable information of potential restoration or donor sites, and HS maps will highlight, from a physico-chemical perspective, additional uncolonised sites where restoration and habitat creation might be feasible.

How to deliver restoration

Ulster Wildlife hosted a virtual workshop on the 17th February 2021 and was attended by 84 representatives from NGOs, academic institutions, government agencies and local councils. The objectives of the workshop were two-fold. The first was to share knowledge about the practicalities of blue carbon habitat restoration from those with experience elsewhere in the United Kingdom and Republic of Ireland. We invited 6 guest speakers that shared their lessons learned from restoration projects focused on seagrass meadows, kelp forests, native oyster reefs, and saltmarsh. The second objective was to capture local knowledge of the areas that were identified as suitable for the blue carbon habitats in the modelling exercise.

In summary, the workshop participants agreed that protecting and enhancing current blue carbon habitats should be prioritised, and that wider ecosystem services provided by these habitats should be recognised along with their blue carbon value.

Prioritising habitats

Workshop participants highlighted difficulties surrounding restoration. For some habitats, there is a strong body of evidence to suggest that creation/restoration measures should be possible (see table 6), although success in the UK has been limited. For those habitats where good evidence exists with regard to creation through physical interventions (notably managed realignment of saltmarsh habitat), outcomes of such habitat creation schemes can sometimes be difficult to predict (e.g. with regard to use by a given bird species), and it can take up to several decades for habitat equivalency with adjacent habitats to be reached (though it can equally happen fairly quickly - mudflat can quickly transition to saltmarsh in estuaries with high sediment loads). Restoration efforts are likely to be more successful in areas with existing individuals, however, some restoration and creation methods rely on the sourcing or harvesting of seed or brood stock (e.g. establishing *Zostera* spp. or *O. edulis* beds), and in many cases suitable sources may be scarce or themselves located within existing marine protected areas. However, there may be opportunities to partner with organisations that have expertise or management oversight of these existing resources. It was noted that consistent monitoring and trials are required in an area where considerable potential for restoration exists but it can be challenging to finance and oversee such measures. For example, it seagrass restoration requires monitoring every 2 months for up to 5 years.

Table 6 Restorability of coastal habitats taken from MMO (2019)[4].

NERC Habitat Name	Restorability	Evidence	Confidence
Coastal saltmarsh	High	High	High
Blue mussel beds (*Mytilus edulis)*	Medium	Low	Low
Horse mussel beds *(Modiolus modiolus)*	Medium	Low	Low
Seagrass beds	Medium-High	Low-Medium	Medium

The importance of funding and delivery partnerships

Workshop case studies highlighted the importance of collaborative partnerships required to deliver habitat restoration programmes. Funding for conservation projects is often competitive, sporadic and insecure, but working collaboratively can increase likelihood of securing funding as well as reducing the risk. Furthermore, large-scale habitat restoration is complex and requires a range of expertise (ecological, social science, policy). The workshop was the first step in building potential partnerships for future blue carbon habitat restoration work in Northern Ireland. A list of potential partners is in table 7.

Table 7 Potential partners in Northern Ireland for blue carbon habitat restoration projects. This list is not exhaustive.

Government & Government Bodies	NGO's	Research and Academic Institutes	Other
Local councils	Ulster Wildlife	Queen's University Belfast	Islander Rathlin Kelp
Department of Agriculture, Environment, and Rural Affairs (DAERA)	National Trust	Ulster University	Bord Iascaigh Mhara
The Crown Estate	Wildfowl and Wetlands Trust	University of Bangor	Royal Yacht Association
Inshore Fisheries Partnership Group	Royal Society for the Protection of Birds (RSPB)	Agri Food and Biosciences Institute (AFBI)	Belfast Harbour
Seafish	Project Seagrass	Geological Survey Ireland (GSI) - LiDAR public feature idenfication	Warrenpoint Port
Centre for Environment Data and Records (CEDaR)	Keep Northern Ireland Beautiful (KNIB)		Angling clubs
The Loughs Agency	Citizen Sea		Seasearch NI / Dive NI

[4] MMO, 2019. **Identifying sites suitable for marine habitat restoration or creation**. A report produced for the Marine Management Organisation by ABPmer and AER, MMO Project No: 1135, February 2019, 93pp

Joint Nature Conservation Committee (JNCC)	Coastwatch		Boat clubs
Strangford Lough and Lecale Partnership (SLLP)			The Peninsula Kelp Company
			Sea Grown
			Maccaferri Solutions
			Anglo North Irish Fish Producers Organisation
			Northern Ireland's Fish Producers Organisation

The role of eNGO's in blue carbon habitat restoration

There are many roles for eNGOs in blue carbon habitat restoration; they can be pilots for larger government projects by their ability to act more quickly than government bureaucracy. The expertise within NGO's can also be used profitably as consultants to environmental authorities. eNGOs are made up of professionals concerned about the environment and have a readymade network of enthusiastic citizen scientists. As such, NGOs have rich human resources that can be used in the conservation of coastal and marine habitats and biodiversity. They also use interpersonal communication methods and have recognised the appropriate community entry points for initiating conversation and establishing trust of the community they seek to benefit. NGOs can facilitate communication upward from people to the government and vice versa and are in the unique position to share information horizontally, networking between other eNGOs and organisations doing similar work as proven by the shared learning during the blue carbon habitat restoration workshop hosted by Ulster Wildlife. They can also act as teachers in public awareness programmes for the community.

NGOs such as the National Trust and the Wildfowl and Wetlands Trust own and manage large areas of the coast and play an important role in managing these areas. They also have the option to purchase land specifically for restoration. Additionally, NGOs can provide technical assistance and training to assist governments and other organizations undertaking similar restoration activities. For example, Ulster Wildlife has expertise in using coir rolls for peatland restoration, a technique that can be applied to coastal wetland restoration.

A Recommended Blue Carbon Action Plan for Northern Ireland

1. Develop a baseline inventory of all blue carbon habitats (table 2) in Northern Ireland: their extent, with local measurement of carbon sequestration rates (CSRs) and estimated total carbon storage by habitat, including understanding how the condition of habitat affects CSR.
2. Review coastal blue carbon habitat current extent and predicted suitability via additional surveys/ground-truthing, where possible identifying habitat condition at each site (which may affect carbon sequestration potential) and any notable local pressures – make use of existing monitoring programmes to gather such data and develop specific surveys for this purpose.
3. Examine historical records (pre 1980) of coastal blue carbon species and habitat extent (e.g. native oyster reefs) and examine how these relate to current habitat suitability models for potentially suitable conditions for these habitats.
4. Implement the five step plan for incorporation of blue carbon protection in existing Marine Protected Areas (see box 2), levering existing policy commitments for this purpose and making MPAs 'climate smart'. Part of this plan would be addressed by steps (1) and (2).

5. Raise awareness of the potential for blue carbon to contribute to Nationally Determined Contributions to greenhouse gas inventory under the Paris Agreement via engagement with policy-makers and the Climate Change Committee.
6. Understand the role of other blue carbon pools, such as sedimentary habitats, within Northern Ireland's waters, and whether these need additional management and protection.
7. Raise public and policy-makers' awareness of blue carbon as a nature-based solution to climate change, including updating the Northern Ireland Marine Plan to strengthen commitment to this approach. Develop a cross-cutting blue carbon strategy that would underpin action to protect, restore, recreate and monitor blue carbon habitats, with priority given to protection and restoration of existing habitats.
8. Identify pilot projects for coastal blue carbon restoration though further development of the blue carbon restoration feasibility GIS (see below), crucially identifying habitat condition and local carbon sequestration rates then prioritising habitats based on their carbon sequestration and storage potential and practicality of restoration actions, exploring the options of co-restoration of habitats, developing partnerships and securing funding. Through this, build capacity locally for blue carbon restoration with flagship local projects to inspire further habitat restoration efforts and demonstrate viability, while also monitoring the co-benefits of habitat restoration such as biodiversity value and erosion protection.
9. Investigate/research the likely response of blue carbon habitats to climate change, especially those coastal habitats that are the current focus for practical restoration.
10. To make the case for restoring coastal blue carbon habitats, ensure a strong understanding (and valuation where possible) of the co-benefits of restoration, such as biodiversity gains, enhancement of other ecosystem services such as flood protection, water quality improvement, and community buy-in/ownership.

Box 2 A five-point plan for improving the protection and effective management of blue carbon ecosystems in MPAs under the CBD in support of the Paris Agreement on climate change (Laffoley, 2020)[5].

6. Recognise the full extent of blue carbon ecosystems present in MPAs
7. Act on operations likely to cause deterioration or disturbance and take the additional management measures needed not to secure blue carbon values of well documented blue carbon ecosystems
8. Map extent and quality of the carbon value of less well documented carbon ecosystems within current MPAs and implement relevant management measures
9. Designate new MPA based primarily on the carbon values for blue carbon ecosystems that lie outside existing MPAs rather than just focusing on traditional biodiversity value alone
10. Take measures to complement the MPAs using tool such as MSP and fisheries management to recognise, protect and best manage blue carbon across seascapes

[5] Laffoley, 2020. ***Protecting and effectively managing blue carbon ecosystems to realise the full value to society – a sea of opportunities.*** An opinion piece by Dan Laffoley for WWF-UK. Woking, Surrey, UK. 42 pp

Introduction

Blue carbon refers to the disproportionate capacity of coastal habitats (predominantly vegetated habitats such as seagrasses and saltmarsh) to sequester carbon dioxide (CO_2) from the atmosphere and incorporate it into biomass which ultimately becomes buried as organic matter within the sediments (Duarte et al., 2005; Fodrie et al., 2017; Macreadie et al., 2019). Organic matter in sediment is exposed to a limited oxygen supply, especially in anoxic sediments, resulting in low degradation rates and a low rate of CO_2 release to the atmosphere. Carbon sequestered in marine habitats is partitioned as that associated with living material, termed 'above ground biomass' (photosynthetic leaves, animal tissue and shell) and 'below ground biomass' (roots, rhizomes) and the non-living material in the sediment, determined as dry bulk density (Di Carlo and Kenworthy, 2008; Fourqurean et al., 2012; Burden et al., 2019; Green et al., 2018; Sousa et al. 2018).

Policy context

Blue carbon may be viewed as a 'triple value' climate solution, simultaneously offering benefits in climate change mitigation, adaptation, and resilience. As a climate action, protection and restoration of blue carbon ecosystems offers a high return on investment across a variety of human and natural impacts. There are a number of policy drivers that have a bearing on how blue carbon ecosystems could be managed within Northern Ireland:

Northern Ireland's Marine Plan

The UK's Marine and Coastal Access Act 2009[6] (MCAA) and the Marine Act (Northern Ireland) 2013[7] required the Department of Agriculture, Environment and Rural Affairs (DAERA) to prepare marine plans, within the framework of the UK Marine Policy Statement[8] (UK MPS). In April 2018 DAERA consulted on a draft Marine Plan[9] which applies to the marine area from the Mean High Water Spring Tide mark to the offshore waters. Although there is no specific mention of 'blue carbon', within the plan there is a core Objective (7) "*To contribute towards climate change mitigation and adaptation measures"* and Objective 6 also makes reference to wider ecosystem services: "*to promote a healthy, resilient and adaptable marine ecosystem and an ecologically coherent network of Marine Protected Areas*."

Under the core policy on Climate Change, the Marine Plan states that "*All Departments and district councils have a collective responsibility in working towards climate change targets and programmes in the exercise of their functions."* (see below). There are specific requirements for "*public authorities and proposers to consider the effects of a proposal on greenhouse gas emissions and consider whether any actions are necessary to adapt to a changing climate".*   The core policy on Coastal Processes is also relevant to blue carbon in coastal habitats, and states that "*Public authorities must consider any potential impact from proposals on coastal processes".*   Carbon sequestration and storage are considered to be ecosystem services, and the maintenance of these is mentioned throughout the Marine Plan (e.g. "*Public authorities should only authorise a proposal, if*

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[6] UK Marine and Coastal Access Act 2009: https://www.legislation.gov.uk/ukpga/2009/23/contents
[7] Marine Act (Northern Ireland) 2013: https://www.legislation.gov.uk/nia/2013/10/contents
[8] UK Marine Policy Statement: https://www.gov.uk/government/publications/uk-marine-policy-statement
[9] Draft Marine Plan for Northern Ireland: https://www.daera-ni.gov.uk/articles/marine-plan-northern-ireland

they are satisfied that any cumulative impacts will not have any likely significant adverse impacts on the marine area, its ecosystem services and the marine users that rely on them").

Future Developments: Northern Ireland's Climate Change Bill, Environment Strategy/Environmental Improvement Plans

On 3rd February 2020, the Northern Ireland Assembly declared a Climate Emergency, following the UK government's similar declaration in 2019. In response to this a commitment was made to progress a NI Climate Change Bill, with options for this consulted upon in early 2021.The Bill would aim to fulfil NI's commitments under the UK Climate Change Act's net zero greenhouse gas emissions by 2050. There is also the development of an Environment Strategy and under the wider UK Environment Bill, a commitment for NI to develop and implement Environmental Improvement Plans. Consultees have responded indicating the need to adopt Nature-based Solutions to climate change (which can also play a role in tackling the biodiversity crisis), with blue carbon listed among these, and further work is ongoing through this project and other initiatives to support development of strategies encompassing blue carbon within NI policy.

UK Marine Strategy

In May 2019, the UK Government launched a consultation on its updated Marine Strategy. Consultees responded by raising an issue regarding Marine Protected Areas (MPAs): "*NGOs asked for areas of importance for carbon storage and sequestration, e.g. seagrass beds, be mapped by 2021 and incorporated into future MPA management and designation*". The written response from the UK Government was: "*Government recognises the crucial role of nature-based solutions for climate mitigation and adaptation, such as the protection and restoration of coastal habitats, including seagrass and saltmarsh. Whilst the primary purpose of MPAs is to protect biodiversity, protecting coastal and marine habitats provides a number of climate related co-benefits for mitigation and adaptation, including improved ocean resilience to the accelerating impacts of climate change, providing coastal protection from erosion and storm surge, and the protection and where necessary restoration of blue carbon habitats and nursery grounds for species of commercial interest and marine conservation importance. We continue to work on developing methods to assess impacts of climate change on MPAs*".

UK Climate Change Act and the UNFCCC's Paris Climate Agreement

The UK is a signatory to the 2015 United Nations Framework Convention on Climate Change (UNFCCC)'s "Paris Agreement", which raised global ambition to limit global warming since the pre-industrial period to "well below" 2°C by 2100, and to make efforts to stay below 1.5°C. As a response to this, and the UK government's declaration of a 'climate emergency', the UK Climate Change Act (2008) was amended in 2019 to commit the UK to a net zero greenhouse gas emissions target by 2050 (rather than the original target of 80% reduction).

Griscom et al. (2017) demonstrated that 37% of the carbon emission reductions needed to meet the objective of the Paris Agreement by 2030 can be achieved by nature-based solutions. There has been considerable focus on the carbon sequestration ability of terrestrial habitats such as forests and peatlands, however the carbon storage capacity of coastal habitats and the ocean is being increasingly recognised.

Although blue carbon is not yet included in the UK's Nationally Determined Contributions (NDCs) to the Paris Agreement, in the first round of NDCs 28 countries included some kind of reference to coastal wetlands in their mitigation actions, while 59 countries included coastal ecosystems or coastal zones in their adaptation strategies. Guidance is also now available for incorporating blue carbon ecosystems in NDCs: https://www.thebluecarboninitiative.org/policy-guidance[10] and it is likely that blue carbon will be considered by the UK (and Northern Ireland) in the NDCs in the near future as part of the strategy to reach net zero by 2050.

International conventions and agreements:

The **Convention on Biological Diversity (CBD)** is a multilateral treaty agreed by 196 countries in 2010, consisting of 20 Aichi Biodiversity Targets to be met by 2020. Aichi Target 15 states that "*By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification*". The rationale for Target 15 is that by restoring landscapes and seascapes we will improve our climate change resilience and carbon storage capacity, and is therefore related to the restoration of blue carbon habitats. Also of note is Target 11: "*By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes*"

The **UN Sustainable Development Goals (SDGs)** were agreed in 2015 providing a comprehensive policy framework to help achieve integration between biodiversity and climate change goals[11]. The **Leaders Pledge for Nature** by political leaders participating in the United Nations Summit on Biodiversity in September 2020, representing 77 countries – including the UK, committed to reversing biodiversity loss by 2030. This denoted a step up in global ambition to reverse biodiversity loss, which is of relevance to the commitment to protection and restoring blue carbon ecosystems.

The **UN Ocean Conference** in 2017 made a further call to action, asking all stakeholders to "*develop and implement effective adaptive and mitigation measures that contribute to increasing and supporting resilience to ocean and coastal acidification, sea level rise, and increase in ocean temperature, and to addressing the other harmful impacts of climate change on the ocean as well as on coastal and blue carbon ecosystems such as mangroves, tidal marshes, seagrass, ….*". We are now in the **UN Decade on Ecosystem Restoration** (2021-2030) which focusses on preventing, halting and reversing the degradation of ecosystems worldwide in recognition of the current critical state of the natural systems upon which life depends. Furthermore, this is the **UN Decade of Ocean Science for**

[10] https://www.thebluecarboninitiative.org/policy-guidance

[11] SDGs 13 and 14 are the most relevant to blue carbon, but other SDG goals have some relevance also (https://www.iucn.org/regions/europe/ourwork/policy/sustainable-development-goals). • 13.1 'strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries.' • 13.2 'Integrate climate change measures into national policies, strategies and planning.' • 14.2 'By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.' • 14.5 'By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information.' • 14.c 'Ensure the full implementation of international law, as reflected in the United Nations Convention on the Law of the Sea for States parties thereto, including, where applicable existing regional and international regimes for the conservation and sustainable use of oceans and their resources by parties.'

Sustainable Development (2021-2030), which aims to enable science to meet some of our biggest societal challenges, including climate change.

The scope of coastal habitats in Northern Ireland to act as 'blue carbon'.

Saltmarsh, seagrass and shellfish beds inhabiting sedimentary habitats all modify the hydrodynamic regime by increasing the surface roughness (see Figure 1 below). This has a damping effect on current velocity and wave action and facilitates particle settlement (Maxwell et al., 2016). These habitats are associated with high levels of fine sediment, plant and animal debris, faecal and pseudofaecal material, and therefore, organic carbon accumulation (Maxwell et al., 2016; Sousa et al., 2018). In shellfish beds, filter feeding removes organic carbon from the water column which becomes sequestered in animal tissues and shell and as faecal and pseudofaecal material in the sediment (Fodrie et al., 2017). Kelp is also thought to represent an important blue carbon habitat through carbon fixation during photosynthesis and subsequent incorporation into plant tissue which ultimately has potential to become sequestered in sedimentary environments (Filbee-Dexter and Wernberg, 2020).

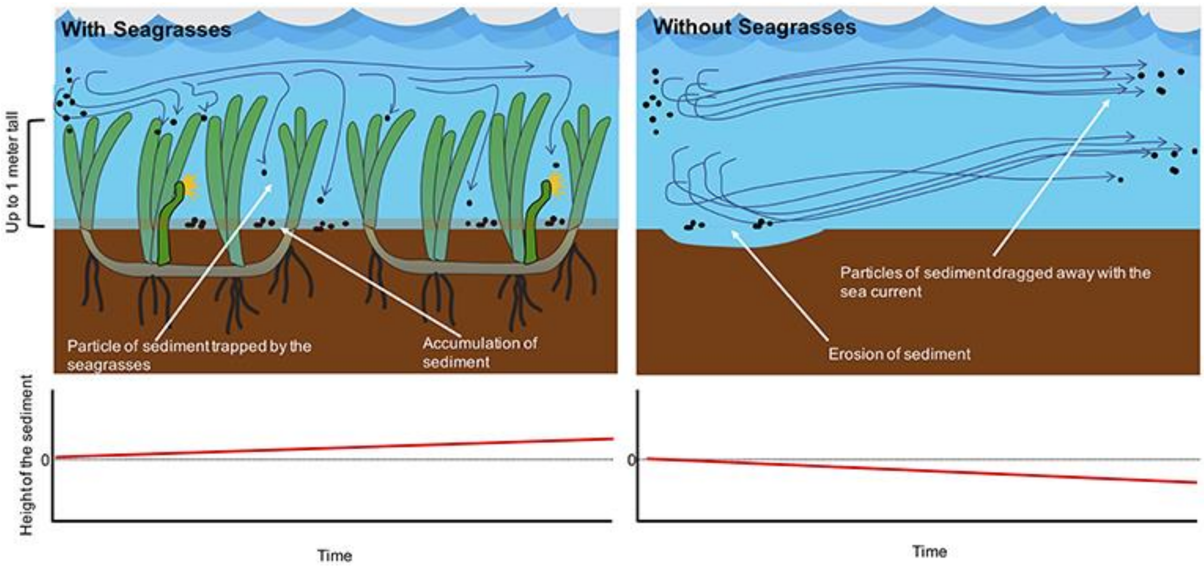

Figure 1. Modification of local hydrodynamic regime by seagrasses, demonstrating sediment accretion and stabilisation over time (© Frontiers for Young Minds, authors Marco Fusi & Daniele Daffonchio)

Seagrass

The significance of the role of seagrass beds in carbon sequestration is now widely acknowledged and subtidal seagrass beds in the UK contribute substantially at the European level (Green et al., 2018). Fourqurean et al. (2012) concluded that seagrass beds were of an equivalent importance to forests in terms of carbon storage capacity, with an estimated global carbon pool of 4.2 and 8.4 Pg (10^{15}) being associated with seagrass beds. However, as forests are vulnerable to carbon release from forest fires, carbon storage within seagrass beds is considered more permanent. Fourqurean et al. (2012) state that whilst seagrass beds occupy just 0.2% of the area of the World's oceans, they account for an estimated 27.4 Tg (10^{12}) carbon burial each year, accounting for approximately 10% of the carbon buried annually in marine habitats. Of the carbon associated with the living tissue, over 60% was found to be associated with the roots and rhizomes, known as the below ground biomass (Fourqurean et al., 2012). Fourqurean et al. (2012) emphasised that carbon storage potential was variable between species with large species, such as *Posidonia* (which has large, long-lived root systems) offering greatest storage potential.

On the south coast of England, Green et al. (2018) estimated sedimentary carbon stocks in *Zostera marina* meadows to be between 98.01 and 140.24 t C ha^{-1} (within the top 100 cm), a value just below the global average of 194.2 t C ha^{-1}. For southern England, this was translated into a standing stock of 66,337 t C (within the top 100 cm), over an area of 549.79 ha and is thought to be equivalent to the annual CO_2 emissions of 10,512 people. This study did not account for living seagrass tissues which have been shown to represent significant carbon sequestration potential.

Saltmarsh

Saltmarsh also has a high capacity for carbon sequestration, with the vast majority being associated with the sediment. In a UK-wide study, Beaumont et al. (2014) estimated the total carbon stock to be 5995 t, with 5413 t being associated with the soil and 452 t being associated with the below ground biomass. Sequestration rates in UK saltmarsh are estimated to range from 64 to 219 g C m^{-2} yr^{-1}, which equates to 8.04 tonnes CO_2 / ha /year (Beaumont et al., 2014). However, the carbon sequestration capacity of saltmarsh is age-dependent with created or restored marshes taking approximately 100 years to achieve the rates of carbon accumulation measured in natural marshes (Burden et al., 2019). Furthermore, in coastal vegetated habitats (e.g. mangrove, saltmarsh and seagrass), sedimentary conditions that favour organic carbon storage (through reducing the rate of aerobic microbial degradation) may enhance the release of other potent greenhouse gases such as methane and nitrous oxide (Roughan et al., 2018; Rosentreter et al., 2021). This issue has been found to be exacerbated in hypernutrified systems (Roughan et al., 2018). Furthermore, excess nitrogen in saltmarsh ecosystems has been found to reduce the below ground biomass leading to accelerated microbial decomposition of organic matter, thus increasing emissions (Roughan et al., 2018). Therefore, there is a high degree of spatial variability and a high degree of uncertainty regarding the role of these habitats in greenhouse gas regulation and climate change mitigation.

Shellfish beds

Fodrie et al. (2017) and Lee et al. (2020) both describe oyster beds as being a significant carbon sink, although Fodrie et al. (2017) also found that they could act as a source of carbon, depending on location and substratum characteristics. Carbon deposition rates of 21 t C ha^{-1} yr^{-1} were recorded in shallow subtidal and saltmarsh fringing oyster beds, respectively, whereas 7.1 t C ha^{-1} yr^{-1} was released from oyster beds on intertidal sandflats (Fodrie et al., 2017). However, these figures suggest that accumulation outweighs loss. Lee et al. (2020) found that oyster beds could enhance sedimentation and carbon deposition three-fold.

Literature relevant to the blue mussel's (*Mytilus edulis*) potential contribution to blue carbon storage is sparse. In optimal conditions *Mytilus edulis* can reach a shell length of 60-80 mm within two years, but in the high intertidal zone growth rate is significantly lower, and mussels may take 15-20 years to reach only 20-30mm in length (Seed & Suchanek, 1992). Standing stock biomass and carbonate production rate will therefore be heavily dependent on local conditions and no single set of values can accurately represent all cases.

Threats to coastal blue carbon habitats

The importance of blue carbon ecosystems in mediating atmospheric carbon dioxide and, hence, mitigation against climate change is now widely recognised (Macreadie et al., 2019). However, there is a long-term trend of coastal habitat loss and degradation through, for example, land claim, benthic fishing activities, alteration of sediment dynamics and eutrophication. For example, Duarte et al. (2008) estimated a global loss of saltmarsh of around 50% whilst Waycott et al. (2009) highlighted a significant rate in the increase of global seagrass loss from 0.9%/year before 1940 to 7%/year since 1990. In the UK, this amounts to between 84 and 92% loss (Jones and Unsworth, 2016).

There are a number of pressures to which coastal blue carbon ecosystems are sensitive:

- Development affecting the intertidal zone, including land reclamation, new sea walls, harbour infrastructure etc., which may physically remove or smother habitat.
- Erosion / changes to local hydrodynamic regimes: this can be driven by natural processes that are altering in response to climate change, as storminess increases, a rise in annual heavy rainfall events, sea level rise and potentially changes to the prevailing wind direction affecting wave fetch and ocean processes. It can also be driven by developments in the intertidal zone which change local coastal processes and can affect local erosion and deposition of sediments.
- ‘Coastal squeeze’ / flood defences: The Department for Infrastructure (DfI) Rivers Agency currently maintains 26km of sea defences in Northern Ireland to protect low-lying coastal lands and infrastructure from flooding. There are also many informal sea defence structures in place by land-owners particularly to protect agricultural land or reclaimed land. Other ‘hard engineering’ within Northern Ireland includes coastal roads and paths which require protection from coastal processes that may erode/undermine these. As above, hard structures affect coastal processes at a local scale, resulting in differing erosion and deposition regimes that will affect the local habitats. Furthermore, as sea level rises, coastal habitats such as saltmarsh will need to migrate inland, which would be natural adaptation, however if there are hard structures inland this will reduce the space available for such change (see Figure 2 below).
- Physical damage / incidental removal of key species: any activity that may harm the structure of the seabed, intertidal zone, or its key species, will affect these habitats, such as dredging, trawling, pot fishing at certain intensities, vessel anchoring, use of vehicles or frequent trampling in the intertidal zone, physical extraction (e.g. kelp harvesting).
- Pollution / water quality: many blue carbon habitats such as seagrass and saltmarsh are sensitive to water quality, in particular nitrogen which may encourage opportunistic algal growth that can smother/outcompete the seagrasses. Light availability is also affected by water turbidity and can restrict/limit seagrass growth.
- Non-native and invasive species: certain invasive species may outcompete native species that are integral to the structure and functioning of blue carbon habitats, for example *Sporobolus anglicus* (formally *Spartina anglica*) in saltmarsh.
- Predation pressure: shellfish reefs can be affected by local predation from, for example, crabs and starfish (mesopredators), and predator dynamics can be critical for establishing reefs.
- Disease, for example the seagrass wasting disease pathogen *Labyrinthula zosterae.*

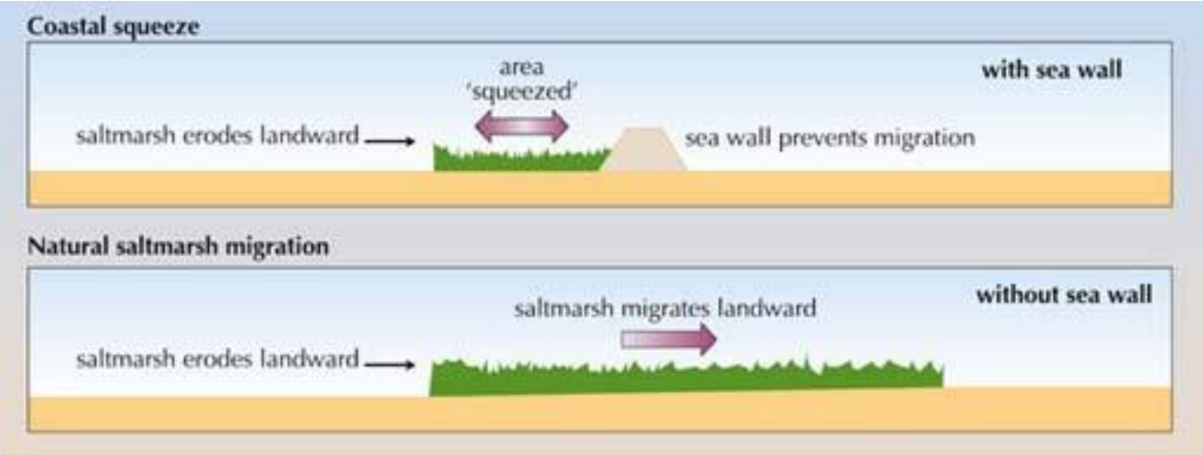

Figure 2. Schematic diagram demonstrating impact of 'coastal squeeze' on saltmarsh migration in response to rising sea levels (adapted from the Environment Agency).

The MarESA database for the sensitivities of specified habitats can be used to compare the sensitivity of one or more habitats https://www.marlin.ac.uk/activity/habitats_report

There is now an urgent need to manage threats to coastal blue carbon habitats, with an emphasis first on protecting existing areas of these habitats, then restoration and finally potential recreation of habitats. At a global scale, restoration is needed for these habitats, in terms of their ecological structure and function, in order to restore their potential for carbon sequestration and climate change mitigation. In particular, there have been widespread efforts in the UK to restore native oyster reefs (e.g. the Native Oyster Restoration Alliance (NORA), the Dornoch Environmental Enhancement Project (DEEP) and the Solent Oyster Restoration Project). Saltmarsh creation and restoration has been achieved through managed realignment programmes undertaken by the Environment Agency and, notably, ABPmer and the National Trust and Project Seagrass (Swansea University) has, for a number of years, carried out research into seagrass restoration techniques and seagrass habitat management.

Project aims and structure of this report

This project aims to assess the feasibility of blue carbon habitat restoration in Northern Ireland inshore waters (to 12nM) via the following objectives:

1. To complete a literature review focussing on subtidal seagrass (*Zostera marina*) to:
   a. Identify suitable conditions for optimum habitat growth (light, depth/elevation, substratum type, hydrodynamic regime, salinity, nutrient loads, suspended sediment load);
   b. Support creation of habitat suitability models for habitat restoration in Northern Irish inshore waters, based on environmental conditions;
   c. Identify threats and sensitivity of *Z. marina* to human pressures;
   d. Review restoration options for *Z. marina*, identifying the positive and negative aspects of each.

2. Using a habitat suitability modelling approach to:

a. Generate maps of the **current extent**[12] for coastal species and habitats that contribute to blue carbon (BC) dynamics in Northern Ireland;
b. To provide predictive maps of **habitat suitability** (HS) for coastal species and habitats that contribute to BC dynamics in Northern Ireland;
c. To identify the **suitable environmental conditions** for species and habitats that contribute to BC dynamics in Northern Ireland.

3. Hold a workshop to examine case studies of coastal blue carbon habitat restoration projects within the UK and bring together a range of stakeholders - government regulators, land-owners, managers and advisors, university researchers, and Non-Governmental Organisations - to consider how restoration of such habitat could work in Northern Ireland, identifying barriers and opportunities.

The coastal species and habitats considered by the project were:

- Three kelp species – *Laminaria hyperborea, Saccharina latissimi* (formerly *Laminaria saccharina*) and *Laminaria digitata* that are all in the Laminariaceae family.
- Subtidal beds of *Zostera marina* and intertidal *Zostera noltei*.
- Saltmarsh – based on the occurrence data provided, it was not possible to differentiate native saltmarsh and that containing invasive *Sporobolus anglicus* (formally *Spartina anglica*)[13].
- European flat Oyster (*Ostrea edulis*) and blue mussel (*Mytilus edulis*).

The selected species and habitats include both BC sources (e.g. kelps that fix carbon) and BC sinks (e.g. bivalves that store carbon) as well as some habitats that are both, e.g. saltmarsh and seagrass. It is important to consider the linkages and connectivity between both BC sources and sinks when considering BC dynamics.

The literature review focused solely on subtidal seagrass due to the timeframe and budget constraints of the project.

This report is structured according to the project aims, with Part I focussed on seagrass restoration consideration, Part II focussed on current extent and predicted habitat suitability for the focus blue carbon habitats, Part III focussed on the findings of the workshop, and finally a recommended Action Plan for Blue Carbon Restoration in Northern Ireland.

[12] The extent of a species is taken to be its distribution during a recent period - a period between 1980 and 2020 for this study. Restricting this period to more recent periods quickly diminishes the number of observations available for producing maps and training HS models.
[13] The observations of saltmarsh provided by CEDaR and DAERA did not specify the species composition of the saltmarsh report, hence it is not possible to separate native and non-native saltmarsh assemblages.

Part I: A review of seagrass (*Zostera marina)* restoration potential

Seagrass beds are amongst the most productive and diverse coastal marine ecosystems on earth (Davison and Hughes, 1998; Jones and Unsworth, 2016; Duarte et al, 2018; Unsworth et al., 2019). They are classed as foundation species or ecosystem engineers which modify sedimentary environments to provide a complex, three-dimensional habitat (Davison et al., 1998; Borum et al., 2004; Duarte et al., 2018). The root structures and leaves create a three-dimensional habitat, providing food and a substratum for attachment, protection from predators and protection from irradiance (Davison and Hughes, 1998; Borum et al., 2004; Jackson et al., 2013). In particular, seagrasses in the UK support intrinsically valuable species such as the seahorse (Jackson et al*.,* 2013) and provide important feeding and nursery grounds for invertebrates, fish and wildfowl (Jackson et al., 2013; Duarte et al, 2018; Unsworth et al., 2019b). Seagrasses modify local hydrodynamic conditions, reducing current speeds, damping of waves and enhancing sedimentation (Bos et al., 2007; Koch et al., 2009). They therefore not only stabilise the habitat, thus enhancing biodiversity (Borum et al., 2004; Unsworth et al., 2019b), they also offer a means of coastal protection (Davison and Hughes, 1998; Koch et al., 2009; Jackson et al., 2013; Duarte et al., 2018).

Due to their productivity, structural attributes and the biodiversity they support, seagrasses are associated with a number of high value ecosystem services including supporting fisheries (commercial and subsistence), nutrient cycling, sediment stabilization, coastal protection and globally significant sequestration of carbon (Costanza et al., 1997; Waycott et al., 2009; Duarte, 2018; Unsworth et al., 2019b). Costanza et al. 1997 described seagrass beds as one of the most valuable ecosystems on earth.

Distribution of *Zostera marina*

Zostera marina is distributed throughout temperate regions in the northern hemisphere, including the north Atlantic and north Pacific, Mediterranean and Black Seas (Short et al*.,* 2010a). In Canada, Alaska, Greenland and northern Europe, *Zostera marina* extends into the Arctic (Borum et al., 2004; Short et al*.,* 2010a) and also exists as far south as California and Mexico (Short et al., 2010). The species is therefore well within its geographic range in UK waters. It is generally a subtidal species but can also be found intertidally especially on the low shore and in areas of standing water (Short et al., 2010a).

Tyler-Walters (2008) described *Z. marina* as being widespread but patchily distributed throughout the UK, predominantly in southwest of England, the Solent and Isle of Wight on the south coast, Wales, western and eastern Scotland including Orkney and the Shetland Islands. In Northern Ireland, *Z. marina* has been recorded in Strangford Lough (subtidally and intertidally), Carlingford Lough (Portig, 2006), along the Antrim Coast at Glenarm and Carnlough, (recorded from Ulster Wildlife snorkel surveys) Outer Ards Peninsula at Kearney (recorded from Ulster Wildlife snorkel surveys), as well as within the following MPAs: Skerries and Causeway Special Area of Conservation[14] (SAC),

[14] Skerries and Causeway SAC Site Selection Assessment: https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Skerries%20and%20Causeway%20SAC%20Site%20Selection%20Assessment.pdf

Rathlin Island SAC[15], Waterfoot Marine Conservation Zone[16][17] (MCZ), and St John's Point Area of Scientific Interest[18] (ASSI). Portig (2006) reported the *Z. marina* in Strangford Lough (also referred to in Davison and Hughes, 1998) to be in low shore areas of standing water and, in general, the plants were heavily colonised by epiphytic species.

Habitat requirements

Borum et al. (2004) and Jackson et al. (2013) summarised the habitat requirements of northern European seagrass species as:

Light availability: One of the most important factors in regulating seagrass growth. In water, light attenuates exponentially with depth and light penetration is also limited by the presence of suspended solids and phytoplankton in the water column. Exposure to light may also be reduced where epiphytic growth is abundant. The light requirements for *Z. marina* are 11-37% of the in-water surface irradiance and in the UK (specifically England), *Z. marina* is generally limited to depths of 5 m or less. However, in clear waters, where light availability is increased, the species may be found down to 10 m. Generally, *Z. marina* is found to depths of 7m in Northern Ireland. In conditions of sub-optimal light, growth rate and shoot density are reduced.

Physical exposure: The upper depth limit of *Z. marina* distribution is controlled by currents and waves and the associated level of physical disturbance which governs seed distribution, settlement and germination, rhizome spreading, potential for uprooting of plants, turbidity (and therefore light availability), sediment destabilisation and mobilisation and sedimentation rates. It is thought that seagrasses do not exist at current velocities exceeding 1.5 ms^{-1}, although this is a generalisation (Borum et al., 2004).

Substratum characteristics: Seagrasses are found in sediments into which the roots can penetrate and the rhizomes can elongate. In the UK, *Z. marina* is generally found sediments composed of sands and fine gravels (Davison and Hughes, 1998) but can also colonise stony and muddy sediments (Borum et al., 2004; Hiscock et al., 2005; Short et al., 2010a; Jackson et al., 2013). Anoxic conditions in fine grained, organic rich sediments can limit the distribution of *Z. marina* due to the potential for sulphide toxicity (Borum et al., 2004).

Salinity: Seagrasses are found in low, variable and full salinity habitats, although in the UK, most *Z. marina* beds are recorded in variable and full salinity habitats (Jackson et al., 2013).

Temperature: Photosynthesis and respiration are regulated by temperature. Whilst *Z. marina* is distributed throughout Europe, and is therefore adapted to a broad temperature range, local adaptation is not necessarily transferrable to all latitudes. Seagrasses may therefore be vulnerable to

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[15] Rathlin Island SAC Conservation Objectives: https://www.daera-ni.gov.uk/sites/default/files/publications/doe/Conservation%20Objectives%20%282017%29.%20%20Rathlin%20Island%20SAC.%20%20Version%203.1%20-%20amendment%2013.10.2017.%20PDF..PDF
[16] Waterfoot MCZ Conservation Objectives and Potential Management Options: https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Conservation%20Objectives%20and%20Potential%20Management%20Options%20-%20Waterfoot%20MCZ.pdf
[17] Red Bay Seagrass Proposal: http://www.seasearch.org.uk/downloads/Red%20Bay%20Seagrass%20Proposal.pdf
[18] St John's Point ASSI citation documents and Map: https://www.daera-ni.gov.uk/sites/default/files/publications/doe/St-John%27s-Point-ASSI-citation-documents-and-map.pdf

temperature shock (Massa et al., 2009). The optimum temperature for *Z. marina* growth is thought to be 10-15°C (Jackson et al., 2013).

Nutrients: Are essential for seagrass growth but, in excess, can promote epiphytic and excessive algal growth resulting in light deprivation, smothering and anoxia within the sediments upon decay.

Biological interactions: the blue mussel *Mytilus edulis* is commonly associated with seagrass beds and can compete for space, supress plant growth and modify the sediment through the deposition of shell and pseudo faeces (Borum et al., 2004). Additionally, predation of seeds and seed burial/ uprooting of plants arise from interactions with macrofaunal species (Short et al., 1996). However, whilst a number of studies (e.g. Sousa et al., 2017) have reported negative interaction between seagrasses and benthic species, Gagnon et al. (2020) highlighted the importance of infaunal an epifaunal bivalves, in particular in maintaining conditions suitable for seagrasses. For example, filter feeding and bioturbation/sediment irrigation and nutrient regeneration has been reported to maintain favourable turbidity conditions and alleviate anoxia in the sediments whilst seagrasses provide shelter, stabilise the sediment, provide protection form physical disturbance and enhance oxygen concentration in the water column, thus benefiting infaunal and epifaunal species. Grazers on seagrass species play an important role in controlling epiphytes (Jackson et al., 2013; d'Avack et al., 2014).

Global decline and threats to *Zostera marina*

The decline of seagrass is a globally acknowledged problem and is predominantly related to anthropogenic activities and pressures (Borum et al., 2004). van Katwijk et al. (2016) described seagrasses as being amongst the most highly threatened ecosystems on earth although, globally, the IUCN classifies *Zostera* species as being of 'least concern' (Short et al., 2010a;b). However, in the North East Atlantic (OSPAR) region, seagrass beds are considered to Near Threatened to Critically Endangered (Gubbay et al., 2016). Waycott et al. (2009) highlighted a significant rate in the increase of global seagrass loss from 0.9%/year before 1940 to 7%/year since 1990. In the UK, this amounts to between 84 and 92% loss (Jones and Unsworth, 2016).

Although wasting disease (*Labyrinthula*) is documented to led to 90% loss of seagrass in Europe, including widespread loss in the UK 1930s (e.g. Borum et al., 2004; OSPAR, 2009, Waycott et al., 2009; van Katwijk et al., 2016), subsequent losses are almost entirely attributed to human pressures, particularly those influencing nutrient loading, siltation and mechanical disturbance (Borum et al., 2004; Jones and Unsworth, 2016). In the UK, subtidal seagrass beds are classed as nationally scarce and are thought to have declined in range by between 25-49% over the 25- year period spanning the 1980s to 2005 (Hiscock et al., 2005). Furthermore, only 20 of the 155 estuaries where subtidal seagrass had been recorded in the 1920s retained beds of more than 1 hectare in 2005; a loss of 85%. In common with other studies, Hiscock et al. (2005) also highlights a lack of data on the current distribution of subtidal seagrass beds and suggests this may mean that significant losses are not being recorded, leading to an underestimate of the overall scale of loss.

Seagrass loss can occur as a result of natural processes including disease, natural changes to habitat structure in dynamic environments, biological interactions, storms and tectonic activity, although the latter is not relevant in UK waters (Short and Wyllie-Echeverria, 1996; Borum et al., 2004; Orth and McGlathery, 2012). However, anthropogenic pressures have played a significant role since the latter half of the twentieth century (Short and Wyllie-Echeverria, 1996). Pressures and threats affecting seagrasses are summarised in detail by Davison and Hughes (1998), Short and Wyllie-

Echeverria (1996), Borum et al. (2004), Hiscock et al. (2005) Jackson et al. (2013) and van Katwijk et al. (2016).

Water quality

Eutrophication is considered a major cause of seagrass decline in many parts of the world (Cabaço et al., 2008; Jones and Unsworth, 2016). Increased nutrient concentrations in the water column, arising from diffuse run off and point source discharges (e.g. sewage and aquaculture) is widely associated with seagrass decline (Davison and Hughes, 1998; Borum et al*.,* 2004; Jackson et al., 2013). Excess nutrients in the water column leads to excessive macroalgal, phytoplankton and epiphytic growth which compete for light and nutrients, thus reducing seagrass growth (Borum et al., 2004; Jackson et al., 2013; Jones and Unsworth, 2016). Increased phytoplankton concentration in the water leads to increased turbidity, further limiting light (Davison and Hughes, 1998). Dense opportunistic algal mats can smother seagrass beds and lead to anoxia and high levels of sulphide in the sediment upon their decay (Borum et al. 2004). Sulphide is toxic during periods of oxygen deficiency in the water column, which results in root anoxia. Under these conditions, oxidation of sulphide to sulphate (non-toxic) is prevented leading to toxicity (Borum et al*.,* 2004).

The impact of chemical pollution on seagrasses has not been widely studies although terrestrial herbicides and marine biocides have the potential to reduce *Zostera* growth (Jackson et al., 2013). Borum et al. (2004) state that seagrasses tend to be relatively resistant to chemical pollution in the form of organic compounds and heavy metals. In the event of an oil spill, intertidal seagrass beds may be susceptible to smothering and the effects of oil degradation, depending on the nature of the oils and circumstances of the spill (Davison and Hughes, 1998). Subtidal seagrasses beyond a certain depth threshold may not come into contact with oil due to its buoyancy (Davison and Hughes, 1998), although light penetration may be temporarily limited. d'Avack et al., (2014) also stated that seagrass beds could be damaged due to trampling and vehicular access during a clean-up operation.

Physical disturbance and changes to the substratum

Zostera species are highly vulnerable to human activities, especially those resulting in direct habitat loss or physical disturbance in the form of surface and sub-surface abrasion, physical removal and loss or change to the habitat (Campbell and McKenzie, 2004; Cabaço et al., 2008). Such disturbance arises from construction work (pipelines, flood defence works, offshore windfarm cable routes, harbour works), moorings (Eriksson et al, 2004), quad bikes, trampling, dredging, benthic trawling and hydraulic dredging, bait digging, and beach nourishment schemes, for example (Foden and Brazier, 2007). Physical disturbance can lead to the direct uprooting of plants leaving bare sediment (Davison and Hughes, 1998). For example, scour around boat moorings can leave circular or semi-circular patches of bare sediment ranging in size from 3-300 m^2, depending on boat size (Jackson et al., 2013). Construction work can destabilise sediments and result in changes to the local hydrodynamic regime, ultimately increasing the chances of scour or increased erosion or increased sedimentation and potential for smothering (Short et al., 1996; Cabaço et al., 2008).

Seagrasses have a dampening effect on current speeds and enhance sedimentation (Maxwell et al., 2016). Physical disturbance results in losses and habitat fragmentation which can reduce these effects and can lead to increased erosion, scour around isolated plants and result in further loss (Davison and Hughes, 1998; Borum et al., 2004; Jackson et al., 2013).

Climatic and hydrological change

It is widely acknowledged that in global terms, the combination of climate change driven increases in water temperatures, rates of sedimentation and turbidity (from increased rainfall and surface run-off), acidification and storminess will have an overall negative effect on range and distribution on seagrasses (Borum et al., 2004). Although intertidal species are more susceptible to temperature extremes (d'Avack et al., 2014) and temperature shock (Massa et al., 2009), than subtidal species, it is of note that Portig (2006) reported widespread *Zostera marina* in the intertidal areas of Strangford and Carlingford Lough. Sea level-rise and coastal squeeze is a particular threat as more than 70% of coastlines worldwide are projected to experience a change of c20% (Borum et al., 2004; Duarte et al., 2018). Whilst loss of intertidal area will affect intertidal species, subtidal species may be impacted by changes in circulation, tidal amplitude, current and salinity regimes, coastal erosion and water turbidity (Borum et al., 2004). There is evidence that seagrasses may benefit from increased dissolved carbon dioxide in seawater, putting them at a competitive advantage over macroalgal species. Conditions of enhanced CO_2 (and, hence, reduced pH) have been associated with increased autotrophic growth (Falkenberg et al., 2013), increased reproductive output (Sunday et al., 2016), increased vegetative shoot production and increased biomass (Palacios and Zimmerman, 2007). However, Sunday et al. (2016) emphasised that decreased seagrass biomass has also been associated with decreasing pH, and in some cases, no effect is observed at all. Therefore, the response of seagrass to changes in CO_2 and pH regime are considered to be site-specific, variable and poorly understood. The projected increase in storm frequency presents a risk of increased turbidity, increased freshwater flow, increased physical disturbance and the potential for plants to be uprooted and an increased risk of sediment erosion and smothering (Borum et al., 2004; d'Avack et al., 2014)

Ecological factors

Zostera species are susceptible to wasting disease as demonstrated by the widespread and significant decline throughout Europe and along the Atlantic coast of North America in the 1930s (Borum et al., 2004; OSPAR, 2009, Waycott et al., 2009; d'Avack et al., 2014; van Katwijk et al., 2016). Seagrasses in the UK are susceptible to invasive species, particularly *Spartina* spp., and the seaweed *Sargassum muticum* (Jackson et al., 2013; d'Avack et al., 2014). *S. muticum* is not necessarily a direct competitor but it can it can quickly colonise potentially suitable habitat and prevent *Zostera* from growing or re-establishing in areas of loss (d'Avack et al., 2014). *Spartina* is unlikely to present a major threat to *Z. marina* given its upper shore distribution (d'Avack et al., 2014). In some parts of Europe, grazing by waterfowl and invertebrates can reduce plant growth and remove leaves (Borum et al., 2004).

Interactions with other species may negatively impact on *Zostera* growth. For example, the blue mussel *Mytilus edulis* is commonly associated with seagrass beds and can compete for space, supress plant growth and modify the sediment through the deposition of shell and pseudo faeces (Borum et al., 2004). Additionally, predation of seeds and bioturbation, resulting in seed burial/ uprooting of plants arise from interactions with macrofaunal species (Short et al., 1996; Sousa et al., 2017). However, the activity of benthic species can also facilitate the maintenance of favourable conditions for *Zostera* through nutrient regeneration, maintenance of favourable turbidity conditions through suspension feeding and alleviate anoxia in the sediments whilst seagrasses provide shelter, stabilise the sediment, provide protection form physical disturbance and enhance oxygen concentration in the water column, thus benefiting infaunal and epifaunal species.

In Northern Ireland, eutrophication and, crucially, smothering by opportunistic green algae, has been identified as a major cause of both subtidal and intertidal seagrass decline in both Strangford and Carlingford Lough, with abundant opportunistic green algae being considered a particular threat (Portig, 2006). In areas of dense algal cover, anoxia in the sediment was noted, as a result of decay. In some areas of Strangford Lough, physical disturbance in the form of cockle harvesting, bait digging, trampling (relating to cattle and recreational use of the intertidal) and vehicular damage (tractor tracks) (Portig, 2006). However, these activities are more likely to occur in the intertidal meaning the majority of the subtidal *Z. marina* beds would not be affected. Gibson (2019) identified physical disturbance associated with moorings to be a specific threat in some parts of Strangford Lough and this pressure is relevant to subtidal seagrass beds. Some beds were considered vulnerable in the absence of any apparent pressures due to their small size and, in some areas, *Spartina* was also prevalent (Portig, 2006) although, being an upper shore species, is unlikely to interact with *Z. marina.* It is of note that Portig (2006) focussed on the intertidal and, whilst intertidal *Z. marina* was quite widespread throughout Strangford Lough, nothing was reported on the spatial distribution of extent of subtidal seagrass beds.

Restoration Techniques

There are examples of *Zostera marina* restoration efforts from around the world, one of the most successful being that carried out in Chesapeake Bay by the Virginia Institute of Marine Sciences in the United States (https://www.vims.edu/research/units/programs/sav1/restoration/index.php[19]; https://magazine.wm.edu/issue/2019-winter/splendor-in-the-grass.php[20]). Following losses throughout the twentieth century due to wasting disease and the effects of a large hurricane in the 1930s (Orth and McGlathery, 2012), this project has led to the establishment of over 9000 ha of seagrass beds over the last 20 years and has contributed substantially to research surrounding restoration techniques and challenges. In the UK, the biggest restoration effort has been coordinated through Project Seagrass[21]. A variety of active restoration techniques have been trialled including transplantation of seedlings, sods, rhizome fragments or seed-bearing shoots, reseeding, laboratory culture, habitat enhancement and attempts to manipulate conditions for optimum seed germination (Govers et al., 2017).

Transplantation/ Seedling transplantation

Various transplant methods have been employed with varying success depending on the local environmental conditions (Borum et al., 2004). Orth et al., (1999) successfully transplanted seedlings of *Zostera marina* into various sites that had previously been colonised as part of a large-scale restoration programme in Chesapeake Bay (USA). They reported a high degree of survivorship (73% after 1 month), with rapid increase in percentage cover from 12% to almost 40% within the first 20 months. Orth et al. employed a simple technique of collecting plants form a large donor bed and re-planting unanchored shoots with rhizomes 20-50 mm into the sediment. Planting at an angle retained a degree of sediment compaction which helped to secure the plants. Planting densities were 70 plants / 4 m^2 plot, with plants being spaced a minimum of 15 cm apart.

[19] https://www.vims.edu/research/units/programs/sav1/restoration/index.php
[20] https://magazine.wm.edu/issue/2019-winter/splendor-in-the-grass.php
[21] Project Seagrass: https://www.projectseagrass.org/

Whilst the approach of Orth et al., (1999) was successful in Chesapeake Bay, the authors acknowledge that the technique is labour intensive (requiring SCUBA at some depths), both from a donor plant collection and a transplantation point of view, and that unanchored plants would potentially be susceptible to storms, strong currents and wave action. They stated that plants would be particularly at risk from physical disturbance during the first week of planting. In areas of high hydrodynamic energy or where fishing activities or other forms of physical disturbance were not controlled, anchoring was recommended.

Some restoration projects have used a frame (either of natural or man-made materials and bags) to secure shoots in place or TERFS (Transplanting Eelgrass Remotely with Frame Systems) that can be deployed more remotely without the use of SCUBA (e.g. Novak et al., 2017; Leschen et al., 2010; Tanner et al., 2010). Further intervention is required to remove frames unless they are constructed from natural biodegradable materials. Kidder et al., (2015) stapled eelgrass plants into the substrate using biodegradable bamboo skewers and highlighted that whilst this was successful, the technique was laborious and required specialist workers. The alternative considered, securing seedlings to a frame (e.g. wire) before transplantation as a means of retaining seedlings in-situ, could result in plant loss or damage when the frame was removed. They trialled biodegradable gird (made from spruce rails and sisal twine weighted with sandbags) that could be left in situ and found these to more successful for plant establishment and subsequently prevented any plant losses due to grid removal.

Metal or bamboo staples bent into a U-shape to secure bare root plants in place are another way of securing plants (e.g. Kidder et al., (2015); Li et al., 2014; Thom et al, 2012; Orth et al., 1999) and shoots can also be planted in sediments without any additional support (e.g. Ruesink, 2018; Davis and Short, 1997). The peat pot method involves removing cores of sediment and plants and placing them into holes in the new bed but requires further intervention to cut down the pots to allow rhizomes to spread (Borum et al., 2004). Plants can also be harvested from donor beds in cores encased in their own sediments ('plugs' in Borum et al., 2004) and are planted in holes in the new bed as sods or plugs (e.g. Paulo et al. 2019) or shoots can tethered to materials that act as anchors to retain their position whilst they establish (e.g. oyster shells, Lee and Park, 2008; stones, Zhou *at al*., 2014).

Some workers have trialled transplant methods to determine which was best in term of promoting eel grass survivorship and productivity under local conditions before commencing full restoration. Park and Lee (2007) trialled three methods on the South Korean peninsula with varying substrate types. Koje Bay sediments had high sand content (84.9% sand +/- 1.3%), Kosung Bay had muddy sediments (96.1% clay ± 0.4 %) and Jindong Bay had loamy sediments (sand 39.9% +/-13.2 and silt 42.9% +/- 13.2%). Across all sites, the staple method showed the highest survivorship of shoots after 4 months (77.1–93.8%), the TERFS (Transplanting Eelgrass Remotely with Frame Systems) with shoots attached to a frame also resulted in relatively a high survival rate (58.7–69.0%). However, anchoring eelgrass onto oyster shells had high survival rates in muddy (81.3%) and silty sediments (76.5%) but very low in sandy sediments (5.0%). The authors highlighted the difference in labour as a consideration for deploying restoration over large areas, with the oyster method being regarded as suitable for large scale deployment in muddy areas as it was less labour intensive.

On the Atlantic coast of Portugal, in two bays in the Arrábida Natural Park, Paulo et al., (2019) trialled three methods of transplantation into bare sediment areas. Firstly, they secured shoots with staples, secondly the use of mesh frames and finally the use of sods (plants in their natural sediments) for eel grass fixation. During this study, all methods apart from the use of sods, failed within the first 3 month of transplantation leaving 'plug' transplantation as the only viable option for transplantation at their sites. Colonisation succeeded for *Z. marina* and only one large plot (11m^2 at establishment) persisted and increased in area to 103m^2 over 8 years. The small plots established in this study (0.04 m^2) had failed at the end of the first winter, and the authors cite grazing by fish and extreme storm events as the main causes for the lack of establishment in other areas. Paulo et al., (2019) also highlight that there appears to be a minimum size of plot to use (6m^2 in this case) to promote stability of plots.

Zhou et al., (2014) also demonstrated high transplant success by attaching 3 shoots with rhizomes to small stones gathered from the local environment and using them as anchors planted 2-4cm depth within the sediment parallel to the surface. After 3 months, 95% of the transplants had survived and 2-3 years later, experimental beds had no statistical difference in shoot density, shoot height and above ground biomass from that of local natural populations. The authors state the method is environmentally friendly (using local materials and biodegradable cotton for attachment) and quick to deploy. However, a simplified transplantation method leaving stones on the sediment surface rather than burial resulted in lower survivorship in the first 2 months (83.9% +/- 9.8%) but after the initial loss plants became established and formed beds, producing potential for further reductions in labour costs.

Seasonal transplant experiments were conducted in Jindong Bay, South Korea by Li et al., (2014) using divers to staple shoots at a density of 32 shoots m^{-2} in October, July, December and March. The new beds were then monitored for 3 months. The summer plants had all died by the end of the sampling period, whereas those planted in autumn (October) reached at density of 75 shoots m−2 at the end of the 3-month period (234% of the initial planting density). Water temperature at the site varied from 4.5 ˚C in January to a peak of 29.6 ˚C during August, and it was this high temperature the authors suggested had resulted in the high mortality of the transplants. They recommended that transplantation should not occur if temperatures exceeded 25 ˚C.

A similar result was reported by Tanner et al. (2010) from restoration attempts using the same transplantation methods at Piney Point in Chesapeake Bay, USA. After successful establishment in fall 2005, high temperatures during summer were thought to be one of the main factors that contributed to the loss of the bed in summer 2007, however low oxygen levels (0-3mg L^{-1}) and low light intensities were also thought to have contributed to the loss. Poor water quality has certainly been repeatedly highlighted as a major factor in lack of success (e.g. Tanner et al., 2010; Borum et al., 2004). Following a period of eel grass loss due to eutrophication and after major works to improve water quality Leschen et al., (2010) transplanted *Z. marina* to the upper reaches of Boston harbour, USA. After 2 years, the biomass and shoot density was equal to or greater than that of natural beds. The greatest success was achieved at sites where the sediment silt/clay content was 35% or less. However, success of colonisation was site specific, despite careful selection. Restoration sites were selected based on modelled data and failure of colonisation was documented at a number of these due to in appropriate sediment type (>57% silt and clay or gravelly substratum), inappropriate hydrodynamic conditions, strong currents than anticipated, abundant macroalgae and physical disturbance from heavy boat traffic and anchoring. They recommended thorough ground truthing but acknowledged that this would be labour intensive and therefore suggested that proper mitigation against the main causes of seagrass losses might be a more effective approach.

Worm and Reusch, (2000) conducted field trials of nutrient availability on the growth rates and survival of small patches of transplanted *Z. marina*. They compared patches treated with slow-release NPK fertiliser, patches with biodeposition from transplanted *Mytilus edulis* to control patches in a low nutrient environment. Results suggest that nutrient availability is not a major factor in eelgrass patch colonization or survival in the Baltic, and their findings showed that nutrient availability did not affect eel grass survival.

Sfriso et al., (2019) reported on an extensive project to restore eel grass meadow at 35 stations within the Venice lagoon. At 31 stations, 37% of transplanted seedings rooted ultimately joining up to form extensive seagrass meadows after 1 year. However, colonisation failed in areas with freshwater input with high concentrations of nutrients or in areas of high suspended particulate matter. The greatest success was achieved in areas where nutrient status and opportunistic algal cover were low, highlighting the importance of appropriate habitat conditions and site choice. Temperature was also a key factor in the survival of *Z. marina* with temperatures <25°C being most favourable as previously reported from both laboratory (Nejrup and Pedersen, 2008) and additional field trials (e.g. Li et al., 2014; Tanner et al., 2010).

Advantages of transplantation

A range of transplant methods are available for establishing new beds, allowing the most suitable method of establishment to be trialled at any one site before full restoration occurs. However, a note of caution here is that most studies only report on the short-term establishment of such areas with the need to perform longer monitoring to ensure success (Paulo et al., 2019). By transplanting material from different donor beds to restore areas it may be possible to increase the chances of transplant success (Novak et al., 2017). Some studies have shown that the success if establishment can very much be influenced by the donor population (Paulo et al., 2019; Novak et al., 2017) and suggest trials be undertaken prior to large scale restoration attempts.

Disadvantages of transplantation

Many of the techniques involve labour intensive methods of both collecting donor plant material and then the subsequent deployment of this in situ and may require SCUBA (Orth et al., 1999; Busch et al., 2010) or then need further intervention to remove frames used in transplantation to allow further development of beds (e.g. Kidder et al., 2015; Leschen et al., 2010). Whilst the approach of Orth et al., (1999) was successful in Chesapeake Bay, the authors acknowledge that the technique is labour intensive (requiring SCUBA at some depths), both from a donor plant collection and a transplantation point of view, and that unanchored plants would potentially be susceptible to storms, strong currents and wave action. In addition, further intervention may be necessary in terms of removal of frames, peat pots or metal wires used as staples unless biodegradable materials are used from the start. Realistically, most of the techniques employed for transplanting shoots or plants are labour intensive (e.g. Zhou et al., 2014; Orth et al., 2009) however, some may need additional intervention. Frames may restrict spread of rhizomes and prevent the formation of larger beds so should be removed after beds have become established (Leschen et al., 2010) or biodegradable materials should be used from the start of the restoration (Zhou et al. 2014; Kidder et al., 2015).

Despite the development of models that may suggest suitable sites for transplants removing some of the need for extensive field investigations, some authors recommend thorough site investigations in addition to such techniques to judge suitability of sites to ascertain their suitability for transplantation (e.g. Tanner et al., 2010; Leschen et al., 2010). Not only should the sediment characteristics and water quality be evaluated, but the potential for long and short-term exposure to stress and disturbance (both natural and anthropogenic) should be considered (Tanner et al., 2010) and action should be taken before any major restoration projects to limit anthropogenic disturbance (e.g. Paulo et al., 2019). In some instance, the lack of success of restoration has led some authors to comment that any such interventions should not be undertaken until the source of the stress and disturbance has first been removed (Paulo et al., 2019; Tanner et al., 2010).

Collection of the transplanted material may cause stress to the plant with the potential for delayed growth until the rhizosphere has been established (Kenworthy and Fonseca, 1992) and collected material will have suffered damage due to the process of removal, transport and transplantation (Li et al. 2010). In addition, there is concern about the amount of damage removal of rhizomes and plugs may cause to donor beds and the labour-intensive nature of the collection of the transplanted material (Fonseca et al., 1994), especially if the donor beds are not extensive. However, some authors report that collection of material produces little damage to the donor bed (e.g. Orth et al., 1997 in Orth et al. 1999).

Paulo et al. (2019) also highlight that there appears to be a minimum size of plot to use (6m2 in this case) to promote stability of plots over the longer term. It is apparent that, from the literature, most studies on the establishment of eel grass beds only focus on the initial productivity, growth and development of the plots (time scales less than 1 year) and that data on longer term survival is not always available.

Artificial seed germination

The lag between seed release / dispersal and germination has been documented by numerous authors and various strategies have been employed to maintain seeds, collected in Spring, under laboratory conditions in preparation for Autumn planting of seedlings. Tanner and Parham (2010) found that cold storage of seeds (4°C) prior to planting enhanced germination and seedling survival under laboratory conditions.

Liu et al. (2016) found that germination of seeds could be induced under laboratory conditions (aquaria with flowing seawater) and that seedling survival was good as long as acclimation to ambient salinity was incremental. Infantes et al. (2016) found that storing seeds at a salinity of 30 led to decreased germination compared to storage at a salinity of 5 and that higher temperatures (15°C, compared to 5°C) was also more favourable. Xu et al. 2016 found that germination was favoured by higher temperature (15-20°C) and that the optimum salinity for germination in the field was at a salinity of 20. However, they demonstrated that seeds could germinate in freshwater or at low salinities (considered optimal for seed germination) under laboratory conditions and that the seedlings could be transferred to optimum salinities of around 20 to accomplish seedling establishment.

Zhao et al. (2016) and Wang et al. (2017) were able to stimulate shoot growth under laboratory conditions by the addition of copper and iron, respectively, to the water and identified both optimum and toxic concentrations of these potentially limiting nutrients. Both studies proposed metal enrichment as a potentially useful strategy in the cultivation of large quantities of donor plants to support seagrass restoration. However, us of this technique does not appear widely in the literature. Govers et al. (2017) did, however, successfully use copper sulphate in concentrations of 0.2 ppm to eliminate infection of seeds by *Phytophthora* and *Halophytophthora* (fungal-like pathogens), which can inhibit seedling development following germination. They emphasised that in order to ensure correct, effective dosing, seeds should be treated in laboratory conditions.

Re-seeding/Seed planting

Harwell and Orth (1999) highlighted the general poor success of restoration efforts involving reseeding and attributed this to high levels of seed transportation, burial, predation, limitations on spatial scale and the need for seed storage facilities. The settlement and re-suspension dynamics of *Z. marina* seeds mean that they can be easily re-suspended at low current velocities (0.7 cms^{-1}) but can sink towards the bed at relatively high velocities (5.96 cms^{-1}), resulting in retention near the bed, where microtopography can potentially limit dispersal (Harwell and Orth, 1999). As a result (and at the time of this study) restoration efforts had focussed on the transplantation of adult vegetative shoots along with efforts to improve efficiency in terms of labour and cost-effectiveness. However, due to the expense in terms of cost, time and labour, the potential damage to donor populations and the possibility of reducing genetic diversity, the potential for re-seeding has since been widely investigated. van Katwijk et al. (2016) propose seed transplantation as one of most effective methods of restoration.

Re-seeding methods include direct sowing of seeds (manual or mechanical), germination in the laboratory and subsequent transplantation of seedlings, use of hessian or coconut fibre matting or bags to protect seeds and deploying seeds/reproductive shoots in bags attached to anchored buoys to encourage natural release and dispersal.

Seed collection

Collection of seeds for use in planting programmes generally involves collection of reproductive shoots, by hand and subsequent storage and handling in a laboratory setting (Harwell and Orth, 1999). This is labour intensive and laboratory maintenance may need to last 3-5 months which requires infrastructure and expense. Pickerell et al. (2005) overcame this issue by collecting reproductive shoots and deploying them in-situ at the donor site and allowing the seeds to mature and disperse upon release. This technique was proposed as a potentially low cost and effective approach to supporting seagrass restoration efforts based on re-seeding although germination and seedling establishment rates using this technique can be low (Marion and Orth, 2010b) (see section on buoy deployment).

Mechanical harvesting has also been proposed as way of reducing labour (and therefore cost) associated with seed collection although Busch et al. (2010) pointed out that his could be damaging to the donor habitat. Marion and Orth (2010b) trialled this approach, in Chesapeake Bay, using a barge-mounted harvester propelled by paddle wheels. The harvester used horizontal toothed cutting bars to remove the seed-bearing shoots in the upper canopy. The harvested shoots were maintained in flowing seawater until the mature seeds were released. The technique proved successful and with careful design, caused minimal damage to the donor beds. Marion and Orth (2010b) emphasised that, in order to employ this strategy, the donor beds must be large, with high densities of reproductive shoots (100-220 m^{-2} in this study). Seeds must be in plentiful supply at the donor site and aquarium of outdoor storage facilities, with flowing seawater, must be available. The long-term effects on the donor beds of this mode of harvesting were not investigated. Busch *et al*. (2010) also trialled mechanical harvesting in Chesapeake Bay and concluded that, whilst material collection rate and volume were improved, inefficiencies in the cutting technique led to a large amount of non-reproductive plant material being collected. Deploying a mechanical harvester was logistically more difficult than collection of reproductive shoots by hand, via snorkelling or SCUBA.

Broadcasting / direct sowing of seeds

Busch et al. (2010) compared different collection and sowing techniques and concluded that collection of reproductive shoots in Spring allowed immediate deployment in the field without the need for storage, which reduced the number of seeds lost due to processing and reduced labour costs. However, in Chesapeake Bay, germination does not occur until October meaning that seeds were left in the sediment for some 4 of 5 months and were susceptible to resuspension, burial and predation. The use of mechanical seed dispersers in the autumn, sowing seed which had been collected and stored, ensured germination shortly after sowing. This reduced seed loss but was expensive. Marion and Orth (2010) reported the greatest germination and seedling establishment success in seeds which had been collected in spring, stored under laboratory conditions with sowing being carried out shortly in advance of germination -October in Chesapeake Bay where the study was conducted. Thus, timing is crucial if unprotected seeds are to be sown.

Marion and Orth (2010) reported low seedling establishment in the presence of *Ruppia maritima* and proposed that reseeding should preferably be in areas of bare sediment although these authors did not comment on the effect of planting seeds within existing *Zostera* beds.

Burial

Resuspension and loss of seeds following sowing has been widely reported as a barrier to successful restoration via re-seeding (Harwell and Orth, 1999; Marion and Orth, 2010, Infantes et al., 2016; Wang, et al. 2016; Sousa et al., 2017). Burial of seeds upon sowing can enhance germination success (Marion and Orth, 2010), with success being enhanced 2-6 times in a Swedish study (Infantes et al., 2016). Infantes et al. (2016) indicated that unless seeds were buried by 2 cm of sand, seeds would be vulnerable to predation and resuspension.

However, other authors report negative effects of seed burial where seeds buried below an optimum depth do not germinate. For example, Wang et al. (2016) recorded a germination rate of between 76 and 90% for seeds sown either at the surface of to a depth of 1 cm, with deeper burial resulting in less than 40% success. Germination of seeds at deeper depth (5cm) was dependent on sediment type with a sand : silt mix (2:1) being the optimum sediment type. Bioturbation by the lugworm *Arenicola marina* has been reported to increase seed burial, with negative effects on germination (Sousa et al., 2017).

Mechanical planting

Orth et al. (2009) stated that low rates of seedling establishment (commonly <10%) were a particular challenge in Chesapeake Bay and trialled a mechanical planting technique to increase seedling establishment compared to simply broadcasting seeds on the sediment surface (whether that be mechanically or manually). Results were variable between sites indicating that this technique may have potential for success in some areas but not others. The lowest rates of seedling establishment were recorded from relatively exposed areas which were exposed to winter storms and had sandy sediment with little biogenic structure.

Deployment of reproductive shoots from buoys

Pickerell et al. (2005) found that viable seeds could be produced from detached, floating reproductive shoots and that this may reduce the cost associated with seed storage and maintenance, requiring laboratory facilities, prior to sowing. Pickerell et al. (2005), Busch et al.

(2010) and Marion and Orth (2010) attempted to deploy reproductive shoots of *Z. marina* in mesh bags (in the Peconic Estuary, New York and Chesapeake Bay, Maryland, respectively) attached to buoys as a means of enabling the release and dispersal of seeds in situ. Pickerell et al. (2005) highlighted this approach as potentially beneficial in situations where source populations are at distances from the restoration site that prevent natural dispersal and colonization. Pickerell et al. (2005) reported a recruitment rate of 6.9% which, although apparently low, was within the range of <1-40% reported by other authors cited by these authors. However, Busch et al. (2010) and Marion and Orth (2010b) concluded that low rates of seedling establishment, labour requirements and logistical challenges made this technique unviable. Furthermore, deployment of reproductive shoots in spring (immediately after collection) left the seeds vulnerable to predation, burial and hydrodynamic processes reducing potential for germination and seedling establishment.

Deployment of seeds in hessian bags

The re-seeding techniques described so far have either been associated with high levels of seed loss through predation, resuspension and burial, all resulting in poor germination success and/or been associated with excessive costs in terms of labour, equipment, boat time and laboratory facilities. Furthermore, in order to germinate, seeds need to remain above the redox potential discontinuity (RPD) and also need to remain at a depth that enables the developing seedlings to reach light (Harwell and Orth, 1999). In recent years, many studies have attempted to overcome these issues by deploying seeds in hessian or burlap bags (Harwell and Orth, 1999; Zhang et al., 2015; Yang et al., 2016; Sousa et al., 2017; Unsworth et al., 2019a) and, overall, this technique has proved to be more successful that deploying seeds from anchored buoys. The method generally involves filling hessian bags with sediment with, in some cases the addition of organic matter or seagrass debris to ensure sufficient nutrients (Unsworth et al., 2019a) and filling the bags with seeds. The bags are deployed in the field and are generally anchored to ensure stability in order for the seedlings to take up root in the underlying sediment. The optimum mesh size is generally reported as 1 mm, which limits seed loss but is large enough to enable penetration by the developing shoots and roots (Harwell and Orth, 1999; Zhang et al., 2015; Unsworth et al., 2019a). In all cases, reproductive shoots were collected and maintained either under laboratory conditions or submerged in bags at the field site (e.g. Yang et al., 2016) until the seeds matured, ready for collection and planting. Yang et al. (2016) also found that exposure of the seeds to temperatures of 4°C, together with a high degree of pore water exchange, significantly enhanced germination and seedling establishment.

Whilst germination and seedling development was achieved in all studies, longer-term survival was variable. For example, Harwell and Orth (1999) initially reported seedling survival rates of 56% for seeds deployed in hessian bags, compared to 15% for seeds sown directly onto the sediment, with laboratory and field trials yielding similar survival rates. However, after 8 months, high rates of sedimentation resulted in widespread mortality. Harwell and Orth (1999) attributed the high level of mortality, in part, to the anchoring of the bags. However, Unsworth et al. (2019a) experienced losses when bags were deployed unanchored. Initial trials in the UK by Unsworth et al. (2019a) also failed because of high rates of sedimentation and development of anoxia, with both studies highlighting the importance of appropriate site choice. Other studies using this technique have reported greater success. For example, Zhang et al. (2015), achieved seedling establishment rates of 16-26% followed by full development and maintenance of seagrass plants during the following 2-3 years, with clonal growth was also being observed and Yang et al. (2016) reported a four- fold increase in plant density two years after deployment. Further trials by Unsworth et al. (2019a) resulted in a seedling establishment rate of 3.5% (reported to be comparable to other studies) but that seedlings had established in 94% of the bags deployed (not accounting for sites where sedimentation prevented seedling establishment).

The method of deployment varies between studies in terms of the materials used, the method of anchoring, the seed density and the bag size. Harwell and Orth (1999) used bags of 5x5 cm filed with 10 seeds whereas Zhang et al. (2015) and Unsworth et al. (2019a) used bags of 120 x 90 cm and 80 x 33 cm, respectively. Zhang et al. (2015) successfully used a seed density of 500 / bag with the bags remaining in place and providing protection for 1.5-2 years before degrading. In contrast, Unsworth found that large bags were not practical to work with and that, after 8 months they had broken up and become fragmented. Unsworth et al. (2019a) achieved greater success using bags 13 x 7.5 cm, with 100 seeds, containing local sediment supplemented with seagrass detritus as a source of nutrients. Harwell and Orth (1999) and Unsworth et al. (2019a) deployed the bags in situ immediately after planning the seeds whereas Yang et al. (2016) maintained the bags in the laboratory until shoots developed.

Using a laboratory flume, Sousa et al. (2017) demonstrated the effectiveness of coconut fibre mats, (3 cm thick) buried at 2cm depth in the sediment, in preventing seed burial. They proposed this as a low-cost and effective restoration technique in areas where seagrasses coexist with bioturbators, such as the lugworm *Arenicola marina.* They proposed that this biodegradable matting should be installed in patches of 1-10 m^2 in order to promote *Zostera* growth and ensure a supply of seeds to enable expansion and recovery of seagrass beds. It is emphasised that this was a laboratory study and in a field situation, disturbing large areas of surface sediment would lead to a reduction in consolidation and stability which could potentially result in seed loss through erosion or smothering. Therefore, the success of this technique is likely to be site-specific and highly dependent on local sediment type and the hydrodynamic regime.

Despite carrying out surveys to confirm habitat suitability in terms of sediment type, depth and the presence of existing seagrass, Unsworth et al (2019) encountered a number of problems and documented low seedling establishment rates in some areas. They emphasised appropriate choice of site (sediment type, hydrodynamics), the possible need for adding seagrass detritus to the bags to ensure sufficient nutrients, anchoring, use of natural biodegradable materials to ensure that the rhizomes can penetrate the hessian and become embedded in the sediment.

Advantages of sowing seeds

- Cheaper and less labour intensive than transplantation (Busch et al., 2010)
- Impact on the donor population is minimised (Borum et al., 2004)
- Seedling establishment can be successful when protected using hessian bags. These bags can offer protection against uprooting of seedlings, seed transportation, burial and predation for 1-2 years and are fully biodegradable. The effectiveness of this approach is dependent on deployment in suitable habitat conditions.
- Re-seeding allows maintenance of high genetic diversity of the restored population.
- Seed loss can be minimised through laboratory storage outside of the growing season.

Disadvantages of sowing seeds

- Collection of reproductive shoots can be labour intensive (Pickerell et al., 2005).
- Lag of 4 or 5 months between seed collection and sowing requires storage facilities, either in a laboratory aquarium or by deploying reproductive shoots in suitable containers outdoors in flowing water.

- Laboratory culture of seeds was labour intensive and expensive and may not be viable for large-scale projects (Yang et al., 2016).
- High degree of seed loss (Infantes et al., 2016 reported up to 96%).
- Low germination and seedling establishment.
- Seed transportation, burial and predation can be high (Infantes et al. (2016) although this problem can be overcome by planting seeds in hessian bags (Unsworth et al., 2019a)

Habitat modification

Unsuitable habitat is documented as a reason for poor restoration success in a number of studies (e.g. Leschen et al., 2010; Unsworth et al., 2019a). The use of dephosphorization slag (a by-product of the steel industry) was mixed with dredged material to form a substrate with favourable particle size for *Zostera marina* that would be potentially more stable under the hydrodynamic regime than dredged material alone (Nishijima et al., 2015). Whist the use of industrial by-products is considered to be an isolated study (based in Japan), the use dredged material in coastal habitat restoration has proved successful in the UK in the context of saltmarsh and intertidal mudflat creation (Bolam and Whomersley, 2005). However, with respect to seagrass restoration, site history and the origin and nature (biogeochemical, particle size, organic content) of the dredged material used must be considered since instability of the newly settled sediment can lead to resuspension and turbidity and high concentrations of ammonia can be toxic to seagrass roots (Kaldy et al. (2004).

Sediment fertilisation (nitrogen and phosphorus) has been proposed as a method of enhancing *Zostera* growth and, in a number of studies, has been successful (Peralta et al, 2003). However, Peralta et al. (2003) noted that increasing nitrogen concentration in the sediment was associated with reduced root biomass. This is an important consideration since long-term establishment and anchoring of plants relies on the development of the root system and, form a carbon storage perspective, the below ground biomass is important for sequestration. Peralta et al. (2003) also suggested that the success of sediment fertilisation in *Z. marina* restoration required a careful balance between fertiliser quantity and light conditions, sediment redox conditions, the addition of sufficient phosphorus to balance ammonium nitrate concentrations and the rate of fertiliser release. Given that this was a laboratory study where these factors could be controlled, the application of this technique is questionable, especially in areas where eutrophication has been or remains a problem given the potential for nutrient release to the water column.

Seagrass restoration feasibility

Challenges to restoration

Challenges to seagrass restoration stem from ecological/environmental, societal, financial and logistical factors. Unsworth et al. (2019a) identified 6 major challenges to seagrass restoration, applicable on a global scale. These challenges relate to poor societal understanding of seagrass systems, their importance, condition and the pressures acting upon them; a lack of research and the need to better understand socio-ecological interaction in relation to seagrass habitats:

1. Societal awareness of seagrass ecosystems and their importance;
2. A need to understand interactions between the socio-economic and ecological elements of seagrass systems;
3. Poor and/or out of date information on the status of seagrasses;

4. A need to understand threatening activities and pressures at a local scale to ensure effective management;
5. A need to target research towards generating scientific information to support conservation actions;
6. A need for improved understanding of the relationships between seagrass and climate change

Of these, two challenges relate specifically to society. Unsworth et al. (2019a) highlighted that, on a global scale, seagrass distribution was poorly understood with many areas of seagrass remaining unmapped. Within the UK, seagrass distribution is reasonably well known in terms of its location but the condition of seagrass in terms of the spatial extent on a local scale and the health of seagrass beds (e.g. shoot density) is less well understood. Information is often out of date and long-term data sets documenting the locations of historic seagrass beds and their decline are limited (Jones & Unsworth, 2016). In Northern Ireland, this information appears to be largely concentrated around Strangford Lough (Portig, 2006) and Waterfoot / Antrim Coast. *Zostera marina* is the protected feature for which the Waterfoot Marine Conservation Zone is designated. There is a well-established list of human activities and associated pressures that pose a threat to seagrass ecosystems (e.g. Borum et al., 2004; d'Avack et al., 2014; Jackson et al., 2013) but these need to be fully understood at a local level and, in the case of seagrass, it is necessary to recognise the importance land use (e.g. due to is influence on water quality) and to integrate this into approaches to conservation and management (Unsworth et al., 2019a).

On a global scale, resources and effort allocated to seagrass conservation are limited. Whilst this may be less of an issue within Europe than in other parts of the world, research effort is required to understand the physical, chemical and biological attributes that result in the provision of ecosystem services. There is also a lack of understanding of the response of seagrass ecosystems to climate change (Unsworth et al., 2019a) which will ultimately influence the success of restoration efforts, however, this is now included in the MarESA sensitivity of selected habitats database which is reviewed when new evidence becomes available.

Financial challenges stem for the expense of surveys required to understand seagrass distribution and condition (Unsworth et al., 2019a) and to ground truth modelled data when assessing habitat suitability. Large scale transplantation schemes are costly and largescale re-seeding schemes require resources in terms of seed collection, storage, germination, field deployment and monitoring (Pickerell et al., 2005; Yang et al., 2016). Overall, Unsworth et al. (2019a) highlighted a lack of funding directed towards seagrass conservation and restoration research, compared to other habitats such as coral reefs.

Monitoring over time to ensure restoration success and long-term establishment is another important challenge in seagrass restoration efforts. This includes the lack of benchmarks to assess success, the long timeframe required and the intensity of sampling and technical skills and expertise necessary. It was discussed at the Blue Carbon Habitat Restoration in Northern Ireland Feasibility study that monitoring is required for 5 years every 2 months.

Importance of habitat suitability

The importance of identifying suitable habitat for *Zostera marina* restoration has been highlighted by nearly every author (e.g. van Katwijk et al., 2009; Leschen et al., 2010; Thom et al., 2012; Sfriso et al., 2019; Unsworth et al., 2019a). Issues with high sedimentation rates, smothering of seagrasses and development of anoxic conditions within the sediment (e.g. Harwell & Orth, 1999; Thom et al., 2012; Unsworth et al., 2019a) and unsuitable hydrodynamic conditions, leading to transportation of seeds, uprooting of seedlings and inappropriate sediment deposition and resuspension regimes (Davison & Hughes, 1998; Borum et al., 2004; Leschen et al., 2010; Thom et al., 2012) have been widely reported. Leschen et al. (2010) also reported inadequacies in habitat suitability modelling as a cause of failure in attempts to restore seagrass beds. Key factors included human activities (heavy boat traffic and anchoring in their study) and abundant macroalgae, in addition to sediment characteristics and current speeds, all of which were either inaccurately modelled or were not included in the model. Within Northern Ireland, many records of *Z. marina* are associated with intertidal habitats (Portig 2006). Although it does occur intertidally (usually in pools), *Z. marina* is essentially a subtidal species and restoration efforts by Thom et al. (2012) were reported to be unsuccessful (in the long term) because of the high level of temporal variation of intertidal habitats in terms of sedimentation, topography and the presence of pools. This variability, particularly in relation to the presence of standing water, suggests that attempts to restore *Z. marina* should focus on subtidal areas.

The scale of restoration projects is an important consideration with larger projects generally resulting in greater success (Unsworth et al., 2019a). Increasing the spatial scale increases the potential for plant survival through spreading the risk. That is, the effect of localised negative influences, such as localised variation in habitat conditions, storms, macroalgal abundance, topographic variability (for example) can be minimised by spatial and temporal variation in planting strategies, as outlined by van Katwijk et al., 2009. At a localised spatial scale, replicate planting in plots at (for example) different depths or elevations, over tens to hundreds of meters, can mitigate against localised variation in habitat condition whereas variation in choice of habitat type (e.g. variation is sediment type, hydrodynamic regime) can improve success at a kilometre scale. Staggered planting between years or on different dates throughout a planting season within a year can mitigate against stochastic events such as storms. This approach to ‘spreading risk’ implies a requirement for large scale restoration.

With respect to scale, Bekkby et al. (2020) stated that high connectivity (dispersal and gene flow) results in greater resilience to disturbance. Clonal growth dominates in beds at the extreme limits of their geographical distribution so beds in these locations can become isolated and vulnerable. It is of note that Northern Ireland is well within the limits of *Z. marina* distribution in a geographical context but localised conditions may represent extreme limits of habitat suitability in term so of sedimentology, hydrodynamic regime, water quality and/or the presence of anthropogenic activities and pressures. Good access to donor populations enhances the chances of restoration success, as does restoring an area where *Z. marina* beds currently exist or previously existed (Orth et al., 1999; Orth & McGlathery, 2012; Rezek et al., 2019).

Successful restoration is generally associated with the removal of human influences associated with seagrass decline, together with recovery of habitat structure and recovery from the legacy of human impacts (van Katwijk et al., 2009; Orth & McGlathery, 2012; Bekkby et al., 2020). Limitation of pressures which restrict light availability (including water quality and factors leading to increased algal growth) is thought to be particularly important (Bekkby et al., 2020) although *Z. marina* is also highly susceptible to physical disturbance. Successful restoration of *Z. marina* in Chesapeake Bay is thought to be related to the general absence of human influence in this area (Orth & McGlathery (2012).

Leschen et al. (2010) and Unsworth et al. (2019a) both acknowledge the value of habitat suitability modelling but, given the sensitivity of seagrass to habitat variables, they emphasised the need for improved biophysical data sets. Restoration efforts have failed where model predictions have inaccurately identified potential sites for restoration (Leschen et al., 2010). Better model parameterisation and thorough ground truthing are recommended but are often prohibitively expensive and labour intensive. In this case, Leschen et al. (2010) recommended that proper mitigation against the main causes of seagrass losses might be a more effective approach.

Wider ecological considerations

Established seagrass beds play an influential role in local sediment dynamics by increasing bed roughness, impeding water flow, encouraging sediment deposition, reducing turbidity and stabilising mobile substrata (even though the roots are usually restricted to the top 20cm of sediment) allowing the development of a diverse infaunal community. Loss of seagrass can result in unfavourable sediment conditions whereby deposition is reduced and resuspension can be increased through scour around isolated or low-density plants (Maxwell et al., 2016). This can lead to regime shifts where changes in the particle size distribution and organic content, changes to deposition and resuspension dynamics, the resultant changes to turbidity and light regime and an overall reduction in habitat complexity can collectively act to prevent recovery of *Z. marina* (Maxwell et al., 2016; Moksnes et al., 2018).

Meysick et al. (2019) emphasized the importance of habitat complexity and interactions amongst ecosystem engineers in the restoration and recovery dynamics of seagrasses. *Zostera marina, Mytilus edulis* and *Magellana gigas* were found to interact with hydrodynamics (generally slowing current speed) and form a physical barrier to seed transportation, thus enhancing seed retention. Furthermore, seed retention was enhanced by the coexistence of *Z. marina* with other ecosystem engineering species. Whilst *M. gigas* is a non-native species in UK waters, it is likely that the native oyster would have a similar positive effect on seed retention. These authors recommended that the beneficial role of co-existing ecosystem engineers should be considered in restoration efforts. Furthermore, Temmink et al. (2020) suggested that restoration efforts could be enhanced by mimicking emergent (group, rather than individual) traits of seagrasses which would facilitate some of these processes. They used biodegradable buried structures, created from potato waste to simulate below-ground root structures and enhance sediment stability, together with aboveground structures to influence hydrodynamics and sediment dynamics in a similar way to seagrass leaves. Transplanting seagrass plants within structures that mimic these functions led to greater survival and yield of seagrass plants.

A number of studies have reported negative interaction between seagrasses and benthic species (e.g. Infantes et al., 2016) whereby bioturbation and predation can result in seed burial or resuspension and overall loss. However, Gagnon et al. (2020) highlighted the importance of infaunal and epifaunal bivalves, in particular, in maintaining conditions suitable for seagrasses. For example, filter feeding and bioturbation/sediment irrigation and nutrient regeneration have been reported to maintain favourable turbidity conditions and alleviate anoxia in the sediments whilst seagrasses provide shelter, stabilise the sediment, provide protection form physical disturbance and enhance oxygen concentration in the water column, thus benefiting infaunal and epifaunal species. This highlights the importance of restoration of the whole system (i.e. associated species) in creating positive feedback loops for long-term maintenance of *Z. marina* beds (Maxwell et al., 2016).

Societal aspects of seagrass restoration

Of the six major challenges to seagrass restoration identified by Unsworth et al. (2019a), two relate to specifically to society, although improved societal understanding of all six factors would be beneficial. These challenges relate to poor societal understanding of seagrass systems and their importance and the need to better understand socio-ecological interaction in relation to seagrass habitats:

1. Societal awareness of seagrass ecosystems and their importance: Unsworth et al (2019a) state that, in order for restoration efforts to succeed, management decisions and the approach to restoration require public support. However, in many parts of the world, there is a lack of knowledge of what seagrasses are and how they contribute to societal wellbeing. A better understanding of these factors within society is not only essential in terms of changing attitudes and behaviour in relation to environmental concerns, it can ultimately put pressure on policy makers to act.
2. A need to understand interactions between the socio-economic and ecological elements of seagrass systems: Within the scientific community, and within certain sectors of society who directly use or rely upon seagrass ecosystems (e.g. coastal fishing communities), the value of seagrass meadows to society is widely acknowledged. In order to achieve sustainable use of seagrass ecosystems, and also to facilitate their restoration and recovery, Unsworth et al. (2019a) emphasised the importance of recognising the interconnection between the social and the ecological system. They proposed that management frameworks needed to include humans (and their activities) as part of the ecosystem and that conservation goals needed to be embedded in a broad, multidimensional approach to achieving sustainability that took account of the communities using ecosystems.

In the context of the habitats assessed in this study, every successful restoration project (in terms of initiation of a large project through to evidence of successful restoration) has relied on publicity, education, effective and sympathetic stakeholder engagement and public support (see Tables 15-26).

Recommendations for *Z. marina* restoration

Van Katwijk et al. (2009) identified five guidelines for the successful restoration of seagrass habitats, based on a combination of restoration experiences in the Wadden Sea and worldwide evidence documented in the scientific literature.

1. Reverse habitat degradation, which involves a good understanding of the causes of seagrass decline and an understanding of current pressures to which seagrass is sensitive but which may not have been present at the time of decline.
2. Appropriate habitat selection in terms of depth, light regime, hydrodynamics, sediment type, salinity and degree of shelter.
3. Appropriate donor population. Selection of plants with specific traits for survival is essential (i.e. adaptation to the local environmental conditions), together with maintenance of genetic diversity to facilitate long-term survival.
4. Spread the risk in terms of spatial and temporal variability in planting regime
5. Optimise techniques to account for ecosystem engineering effects of seagrass. For example, anchoring techniques or the use of matting/hessian bags can facilitate plant establishment and promote sediment stabilisation.

Z. marina has a large seed production capacity making seed transplantation an economically viable method of restoration. van Katwijk et al. (2016) propose seed transplantation as one of most effective methods of restoration. Furthermore, the greatest success in reseeding appears to be associated with techniques that minimise seed transportation, predation and burial and maximise the chances of the seedlings taking root. The use of hessian (or similar) bags or matting offers an environmentally sound means of achieving this (Harwell and Orth, 1999; Zhang et al., 2015; Yang et al., 2016; Sousa et al., 2017; Unsworth et al., 2019a).

Overall, successful restoration, including restoration of seagrass spatial extent, shoot density, biomass and the associated sedimentological and biogeochemical processes is a lengthy process, even when habitat conditions are suitable (McGlathery et al., 2012). In Chesapeake Bay, McGlathery et al. (2012) observed a developmental lag between 1 and 4 years after seeding but that parameters associated with *Zostera* bed function and sediment biogeochemistry increased and developed rapidly between 4 and 9 years. Furthermore, the importance of the establishment of belowground biomass has been emphasised in terms of long-term stability and survival of seagrass beds (Peralta et al., 2003) and in the context of carbon sequestration (Fourqurean et al., 2012). Tanner et al. (2020) found that recovery of belowground biomass could take between 4 and 6 years. These observations indicate that any restoration programme needs to involve long-term monitoring.

Part II: Habitat suitability modelling

An Introduction to Habitat Suitability Modelling

Habitat suitability models (also known as, species distribution models, predictive habitat models or environmental niche models) are models that predict the likely distribution of a species or habitat using environmental variables as predictor variables. Habitat suitability (HS) models are widely used in conservation ecology and environmental management. Given the wide distribution for many marine species and habitats and the porosity of biological data, the potential for HS models to 'fill the data gap' has obvious appeal. HS models are increasingly recognised as an effective way to obtain knowledge on both the likely distribution of species as well as identify the suitable, but not currently colonised, habitat for that species. Suitable habitat, when modelled and mapped, will highlight both the current extent of a species but also areas with the appropriate environmental conditions for a specific species but aren't occupied by that species. The reasons why suitable habitat remains uncolonised (or unrealised) may well be due to constraints on dispersal, biological factors (e.g. high predation, competition or disease pressures), or human pressures.

It is highly likely that full coverage products provide the most effective evidence base for site selection processes for an array of marine activities (e.g. designation of areas, restoration, habitat creation, activity zoning etc). With regard to extent, the full coverage outputs from HS models are not a replacement for dedicated field studies and remote sensing techniques that can also be used to establish the current extent of species and habitats. Instead, HS models should be considered as an integral part of an iterative process where the models are used to: (i) summarise and aggregate present data on ocean conditions and distribution of species and habitats; (ii) to inform management decisions, considering the uncertainty of the model output; and (iii) to guide new exploration and scientific efforts that in turn provide data for updated models.

A precautionary approach should be taken when interpreting the maps produced by this study (and generally any HS modelling exercise). It is important to note that it is difficult to model species and habitats that occur intertidally or in shallow subtidal habitats (often termed the 'white ribbon' where bathymetry, and other environmental parameters are often hard to collect and sparse). Intertidal and high shore areas often fall between two stools i.e. they are not sufficiently addressed by terrestrial mapping and modelling products nor marine products. As such, modelling can be hampered by missing or inaccurate predictor variables. Regardless of the challenges, spatial estimates of occupied and potential habitats are essential for habitat restoration and creation site selection. For example, the extent maps provide valuable information of potential restoration or donor sites, and HS maps will highlight, from a physico-chemical perspective, additional uncolonised sites where restoration and habitat creation might be feasible.

Methods

Estimation of Extent and Habitat Suitability

The overall concept used for HS modelling is that occurrence data are used to train a model to recognise suitable environments. The model then extrapolates the suitability across the entire area of the predictor variables. There are five stages within the spatial modelling process:

(i) the gathering of data and production of predictor variables (PV);
(ii) the gathering of presence data and the production of absence data;
(iii) the training of a spatial model using both the predictor variables and presence/absence data;
(iv) the prediction of areas using the trained model; and
(v) the assessment of model performance and validation of outputs.

Gathering the Predictor Variables

Spatial data for use as predictor variables were collected from several sources (Table 1) – example PV surfaces are provided in Figure 3. Some variables needed additional processing, which has been detailed in Table 1. The bathymetry and elevation surfaces were merged to produce a single digital elevation model (DEM) for Northern Ireland (NI) and saltmarsh occurs along the junction of these two datasets. The majority of the data sources for the DEM had a native resolution of 30 metres (Digimap and ASTER elevation), as such, all other inputs into the DEM were resampled to this resolution. Correlation matrices of the predictor variables indicated high levels of collinearity between certain variables. The 'remove Collinearity' function in the R *virtualspecies* package was used to remove correlated PVs before they were used in the models.

Table 1. Predictor variables sourced or created for the modelling of extent and habitat suitability in Northern Ireland. Additional processing steps are detailed in the table. The ArcMap project that accompanies this report holds a copy of all of the predictor variables sources and those produced for this study.

Variable	Source	Processing method
Bathymetry	EMODnet 2021; Edina Digimap; Multibeam data sourced from NI and the United Kingdom Hydrographic Office (UKHO) Data Archiving Centre	EMODnet 2021 (75 m); Digimap (30 m); MBES for Strangford Lough (2 m) variable; whole surface resampled to 30 m. Poor Digimap coverage in Lough Foyle – patched with EMODnet 2021.
Elevation	Version 3 of the ASTER Global Digital Elevation Model (GDEM)	30 m grid for landmass; elevation merged with bathymetry.
Terrain variables – slope, aspect, rugosity (planform), rugosity (profile) and rugosity (total)	Merged DEM	Slope, aspect and rugosity calculated with the Benthic Terrain Modeller in ArcMap (search neighbourhood: 3 x 3 pixels).
Coastal behaviour	EMODnet Geology – 500 m transects along NI coast	Erosive/depositional rates every 500 m interpolated to a 30 m grid.
Substrata	EMODnet Geology – multiscale substrates Strangford Lough substrates from Strong et al. (2016)[1] British Geological Survey rock substrate layer	EMODnet Geology 250 k polygons very poor near shore. Polygons were manually extended to shore in ArcMap. Strangford Lough was substituted for substrates from Strong et al (2016)[22]. A shoreline selection was used to select BGS rock within 1500 m of shore – this was used to substitute existing seabed in the EMODnet surface. Sediment observations labelled on charts of Lough Foyle and Carlingford were digitised. The point substrate observations were aligned with the EMODnet classes. Thiessen polygons were generated using the points and then 'dissolved' based on aligned substrata. Dissolved Thiessen polygons were used to replace gaps in Carlingford and Foyle (an erase and merge cycle).
Wave exposure	EMODnet Seabed habitats[23]	333 m – cokriged into shore with bathymetry using the cokriging tool in ArcMap
Tidal currents	EMODnet Seabed habitats	333 m – interpolated into shore using the 'Focal Statistics' tool in ArcMap
Photosynthetically Active Radiation (PAR) at seabed	EMODnet Seabed habitats	100 m – cokriged into shore with bathymetry using the cokriging tool in ArcMap
Nutrients (nitrate)	ICES Oceanographic Data Centre Surface data[24]	ICES filtered to remove observations from before the Nitrates Directive (112 k observations). Merged with DAERA observations and interpolated with a Kernel Interpolation with barriers.

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22 Strong, J.A., Service, M. and Moore, H. 2016. Estimating the historical distribution, abundance and ecological contribution of *Modiolus modiolus* in Strangford Lough, Northern Ireland. Biology and Environment: Proceedings of the Royal Irish Academy, 116, 1-16.

23 https://www.emodnet.eu/en/seabed-habitats

Variable	Source	Processing method
	– 24 k DIN/Nitrate obs DAERA – WFD database (last five years)	
Salinity	ICES Oceanographic Data Centre Surface data[25] DAERA – WFD database	Interpolation with a Kernel Interpolation with barriers (112 k observations)
Rivers/catchments	Open Data NI[26] HydroRIVERS Version 1.0[27]	The Flow Direction tool; Sinks tool; fill sinks tool; flow direct tool; basin tool; raster to polygons; join river mouth with sea with catchment area.
Aquaculture sites (mussels and oysters)	DAERA Aquaculture sites NI	Aquaculture: native oysters in Lough Foyle only; mussel licenses present for Belfast Lough, Carlingford Lough and Strangford Lough (not currently producing). Cost Distance tool used in ArcMap to estimate the shortest marine route (i.e. with land barriers) to commercial mussel and oyster sites.
Shoreline	UKHO – Satellite derived coastline	Used to clip some features and as a background layer

[24] https://ocean.ices.dk/data/surface/surface.htm

[25] ICES data were selected because DAERA confirmed that all of their historical data was available through this. Copernicus Marine Environment Monitoring Service (CMEMS) products were also examined but the best salinity and NPP model outputs were only provided at a 4 km resolution, which was considered too coarse for the 30 m prediction grids. CMEMS 'historical observations' were not used to avoid having to sort replicated observations that were also present in the ICES data.

[26] https://www.opendatani.gov.uk/

[27] https://www.hydrosheds.org/page/hydrorivers

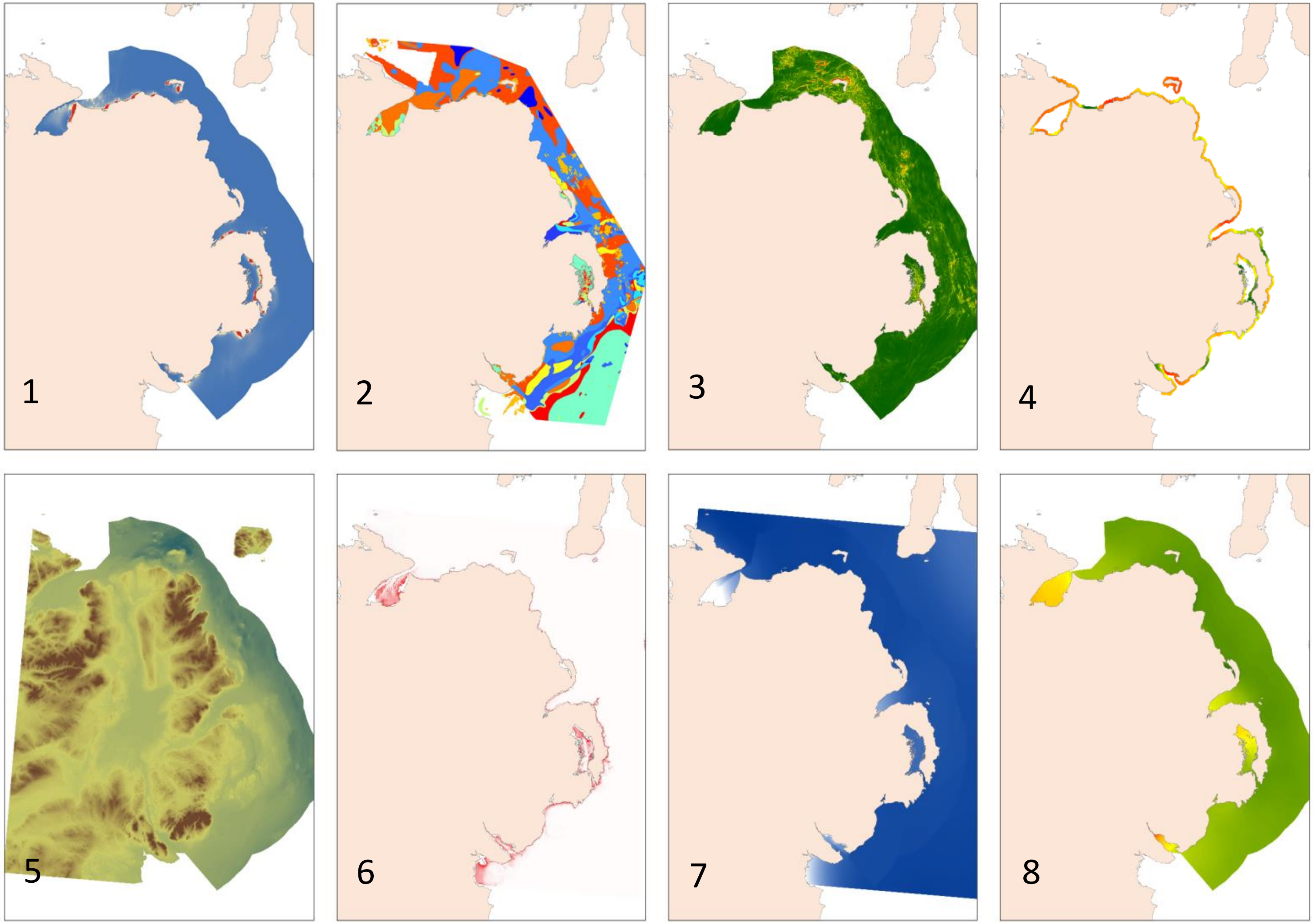


Figure 3. Example thumbnails for the predictor variables used for the HS modelling: 1 = kinetic wave energy; 2 = EMODnet Geology Substrates; 3 = slope; 4 = EMODnet Geology coastal erosional rates; 5 = DEM; 6 = PAR; 7 = salinity; and 8 = mean temperature.

Presence and absence data for species and habitats

Occurrence data were sourced from the Northern Irish Centre for Environmental Data and Recording (CEDaR) database[28] to train the models – a breakdown of this information is provided in Table 2. Additional sources of information were accessed to augment the presence data provided by CEDaR – these sources are detailed in Table 3. Observations from between 1980 and 2020 were used to represent the 'current' distribution. Restricting this period to more recent periods diminished quickly the number of observations available for producing maps and training HS models. It is acknowledged that there have been some significant changes in the population of some of the modelled species over the last 40 years (e.g. erratic population dynamics of *Ostrea edulis* in Strangford Lough – Kennedy and Roberts, 2006). As such, it is clearly a substantial assumption that presence observations collected in the 1980s still present the present distribution.

The modelling method used for this study requires absence data. The strategy for generating absence data was to use observations from a set of biotopes that definitely cannot support each modelled species (these are considered true absence data) – the biotopes selected for each species or habitat are shown in Table 4. The biotope information was sourced from CEDaR and the Marine Recorder Snapshot[29]. In addition to the biotope data, the absences for kelp were augmented with a random set of 800 points (the addition of 800 absence points helped balance the number of presence and absence points in the training dataset) from below the 30 m contour (using the random point tool in ArcMap) (pseudoabsence data). The 30 m contour is widely recognised as the maximum possible depth for any of the Laminariaceae in the UK (see MarLIN[30]).

The presence and absence data were thinned to one majority (majority used in case of mixed presence and absence points at the same location) point per 30 m grid cell. The resulting presence/absence datasets were used to train the Random Forest models. No observations were kept aside for validation due to the difficulties of validating suitability maps (it is impossible to validate highly suitable habitat when it is not occupied). Out-of-bag statistics (data set aside by the model whilst bootstrapping the data) were used to assess model performance (Cutler, 2010).

[28] https://www.nmni.com/CEDaR/CEDaR-Centre-for-Environmental-Data-and-Recording.aspx
[29] https://jncc.gov.uk/our-work/marine-recorder/
[30] https://www.marlin.ac.uk/

Table 2. Species occurrence data provided by CEDaR before and after filtering (marine records (except for saltmarsh) and NI only).

Species or habitat	Records supplied	Marine positioning	NI only	Remaining (%)	Additional sources or notes
Saltmarsh	1748	1748	1748	100%	DAERA observations – six locations NI (133 polygons); JNCC – Strangford Lough from drone imagery (1615 polygons)
Laminaria digitata	1600	988	862	54%	CEDaR only
Laminaria hyperborea	1884	1399	824	44%	CEDaR only
Mytilus edulis	3927	2684	2393	61%	CEDaR and DAERA observations - 22 sites on the eastern shore of Strangford Lough
Ostrea edulis	5625	5443	5392	96%	CEDaR only
Saccharina latissima	2209	1569	1284	58%	CEDaR only
Zostera marina	607	493	405	67%	CEDaR only
Zosterella noltei	681	555	550	81%	CEDaR only

Table 3. Additional biological occurrence data accessed in addition to that provided by CEDaR.

Species or habitat	**Source**
Mytilus edulis (common or blue mussel)	DAERA - 22 sites on the eastern shore of SL
Ostrea edulis European flat oysters	Dave Smyth/DAERA – 52 intertidal and 114 subtidal in SL only
Saltmarsh	DAERA – six locations in NI JNCC's Strangford Lough drone-base aerial survey (provided by Georgia McDowell)
Laminaria hyperborea, Saccharina latissima (formerly *Laminaria saccharina*) and *Laminaria digitata*	DAERA Macroalgae surveys available on OpendataNI
*Zostera marin*a and *Zostera angustifolia* Subtidal and intertidal seagrass species	Ulster Wildlife Trust – Outer Ards bed DAERA – seven sites in NI

Table 4. Biotopes selected as absence data for each species and habitat.

2014 Biotopes	Biotope Description	Seagrass	Kelp	Saltmarsh	Mussels	Oysters
CR_LCR	Low energy circalittoral rock	Absence		Absence		
IR_FIR_SG	Infralittoral surge gullies and caves	Absence		Absence		Absence
IR_HIR	High energy infralittoral rock	Absence		Absence		Absence
IR_MIR	Moderate energy infralittoral rock	Absence		Absence		
IR_MIR_KR_Ldig_Bo	*Laminaria digitata* and under-boulder fauna on sublittoral fringe boulders	Absence		Absence		
LR_FLR_Lic_Bli	*Blidingia* spp. on vertical littoral fringe soft rock	Absence		Absence		Absence
LR_FLR_Lic_UloUro	*Ulothrix flacca* and Urospora spp. on freshwater-influenced vertical littoral fringe soft rock	Absence	Absence	Absence		Absence
LR_MLR_BF_Fser_Bo	*Fucus serratus* and under-boulder fauna on exposed to moderately exposed lower eulittoral boulders	Absence	Absence	Absence		
LS_LMp_LSgr_Znol	*Zostera noltii* beds in littoral muddy sand		Absence	Absence	Absence	
LS_LMp_Sm	Saltmarsh	Absence	Absence		Absence	
SS_SMp_KSwSS	Kelp and seaweed communities on sublittoral sediment	Absence		Absence		
SS_Smu_CFiMu	Circalittoral fine mud	Absence	Absence	Absence	Absence	
SS_Smu_CSaMu	Circalittoral sandy mud	Absence	Absence	Absence	Absence	
SS_SMx_CMx	Circalittoral mixed sediment	Absence	Absence	Absence		
SS_SMx_Imx	Infralittoral mixed sediment	Absence	Absence	Absence		
SS_SMp_Mrl	Maerl beds	Absence		Absence	Absence	
SS_SCS	Sublittoral coarse sediment (unstable cobbles and pebbles, gravels and coarse sands)	Absence		Absence		
SS_Ssa	Sublittoral sands and muddy sands		Absence	Absence	Absence	
CR_MCR_CMus_CMyt	*Mytilus edulis* beds with hydroids and ascidians on tide-swept exposed to moderately wave-exposed circalittoral rock	Absence		Absence		
IR_HIR_KFaR	Kelp with cushion fauna and/or foliose red seaweeds	Absence		Absence		
IR_HIR_KFaR_Ala_Ldig	*Alaria esculenta* and *Laminaria digitata* on exposed sublittoral fringe bedrock	Absence		Absence		
IR_HIR_KFaR_Ala_Myt	*Alaria esculenta, Mytilus edulis* and coralline crusts on very exposed sublittoral fringe bedrock	Absence		Absence		Absence
IR_HIR_KFaR_LhypFa	*Laminaria hyperborea* forest with a faunal cushion (sponges and polyclinids) and foliose red seaweeds on very exposed upper infralittoral rock	Absence		Absence		Absence
IR_HIR_KFaR_LhypPar	Sparse *Laminaria hyperborea* and dense *Paracentrotus lividus* on exposed infralittoral limestone	Absence		Absence		
IR_HIR_KFaR_LhypR	*Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock	Absence		Absence		
IR_HIR_KFaR_LhypR_Ft	*Laminaria hyperborea* forest with dense foliose red seaweeds on exposed upper infralittoral rock	Absence		Absence		
IR_HIR_KFaR_LhypR_Pk	*Laminaria hyperborea* park with dense foliose red seaweeds on exposed lower infralittoral rock	Absence		Absence		
IR_HIR_KSed	Sediment-affected or disturbed kelp and seaweed communities	Absence		Absence		
IR_HIR_KSed_LsacSac	Laminaria saccharina and/or *Saccorhiza polyschides* on exposed infralittoral rock	Absence		Absence		
IR_HIR_KSed_Sac	*Saccorhiza polyschides* and other opportunistic kelps on disturbed sublittoral fringe rock	Absence		Absence		
IR_HIR_KSed_XKHal	*Halidrys siliquosa* and mixed kelps on tide-swept infralittoral rock with coarse sediment	Absence		Absence		
IR_HIR_KSed_XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured / sand-covered	Absence		Absence		

	infralittoral rock					
IR_LIR_K	Silted kelp communities (sheltered infralittoral rock)	Absence		Absence		
IR_LIR_K_LhypCape	Silted cape-form *Laminaria hyperborea* on very sheltered infralittoral rock	Absence		Absence		
IR_LIR_K_LhypLsac	Mixed *Laminaria hyperborea* and *Laminaria saccharina* on sheltered infralittoral rock	Absence		Absence		
IR_LIR_K_LhypLsac_Ft	Mixed *Laminaria hyperborea* and *Laminaria saccharina* forest on sheltered upper infralittoral rock	Absence		Absence		
IR_LIR_K_LhypLsac_Gz	Grazed, mixed *Laminaria hyperborea* and *Laminaria saccharina* on sheltered infralittoral rock	Absence		Absence		
IR_LIR_K_LhypLsac_Pk	Mixed *Laminaria hyperborea* and *Laminaria saccharina* park on sheltered lower infralittoral rock	Absence		Absence		
IR_LIR_K_Lsac	*Laminaria saccharina* on very sheltered infralittoral rock	Absence		Absence		
IR_LIR_K_Lsac_Ft	*Laminaria saccharina* forest on very sheltered upper infralittoral rock	Absence		Absence		
IR_LIR_K_Lsac_Ldig	*Laminaria saccharina* and *Laminaria digitata* on sheltered sublittoral fringe rock	Absence		Absence		
IR_LIR_K_Lsac_Pk	*Laminaria saccharina* park on very sheltered lower infralittoral rock	Absence		Absence		
IR_LIR_KVS_Cod	*Codium* spp. with red seaweeds and sparse *Laminaria saccharina* on shallow, heavily-silted, very sheltered infralittoral rock	Absence		Absence		
IR_MIR_KR	Kelp and red seaweeds (moderate energy infralittoral rock)	Absence		Absence		
IR_MIR_KR_Ldig	*Laminaria digitata* on moderately exposed sublittoral fringe rock	Absence		Absence		
IR_MIR_KR_Ldig_Bo	*Laminaria digitata* and under-boulder fauna on sublittoral fringe boulders	Absence		Absence		
IR_MIR_KR_Lhyp	*Laminaria hyperborea* and foliose red seaweeds on moderately exposed infralittoral rock	Absence		Absence		
IR_MIR_KR_Lhyp_Ft	*Laminaria hyperborea* forest and foliose red seaweeds on moderately exposed upper infralittoral rock	Absence		Absence		
IR_MIR_KR_Lhyp_GzFt	Grazed *Laminaria hyperborea* forest with coralline crusts on upper infralittoral rock	Absence		Absence		
IR_MIR_KR_Lhyp_GzPk	Grazed *Laminaria hyperborea* park with coralline crusts on lower infralittoral rock	Absence		Absence		
IR_MIR_KR_Lhyp_Pk	*Laminaria hyperborea* park and foliose red seaweeds on moderately exposed lower infralittoral rock	Absence		Absence		
IR_MIR_KR_LhypT	*Laminaria hyperborea* on tide-swept, infralittoral rock	Absence		Absence		
IR_MIR_KR_LhypT_Ft	*Laminaria hyperborea* forest, foliose red seaweeds and a diverse fauna on tide-swept upper infralittoral rock	Absence		Absence		
IR_MIR_KR_LhypT_Pk	*Laminaria hyperborea* park with hydroids, bryozoans and sponges on tide-swept lower infralittoral rock	Absence		Absence		
IR_MIR_KR_LhypTX	*Laminaria hyperborea* on tide-swept infralittoral mixed substrata	Absence		Absence		
IR_MIR_KR_LhypTX_Ft	*Laminaria hyperborea* forest and foliose red seaweeds on tide-swept upper infralittoral mixed substrata	Absence		Absence		
IR_MIR_KR_LhypTX_Pk	*Laminaria hyperborea* park and foliose red seaweeds on tide-swept lower infralittoral mixed substrata	Absence		Absence		
IR_MIR_KT	Kelp and seaweed communities in tide-swept sheltered conditions	Absence		Absence		
IR_MIR_KT_LdigT	*Laminaria digitata*, ascidians and bryozoans on tide-swept sublittoral fringe rock	Absence		Absence		
IR_MIR_KT_LsacT	*Laminaria saccharina* with foliose red seaweeds and ascidians on sheltered tide-swept infralittoral rock	Absence		Absence		
IR_MIR_KT_XKT	Mixed kelp with foliose red seaweeds, sponges and ascidians on sheltered tide-swept infralittoral	Absence		Absence		

	rock					
IR_MIR_KT_XKTX	Mixed kelp and red seaweeds on infralittoral boulders, cobbles and gravel in tidal rapids	Absence		Absence		
LR_FLR_Rkp_FK	Fucoids and kelp in deep eulittoral rockpools	Absence		Absence		
LR_HLR_MusB_MytB	*Mytilus edulis* and barnacles on very exposed eulittoral rock	Absence	Absence	Absence		
LR_LLR_FVS_FserVS	*Fucus serratus* and large *Mytilus edulis* on variable salinity lower eulittoral rock	Absence	Absence	Absence		
LR_MLR_MusF_MytFR	*Mytilus edulis, Fucus serratus* and red seaweeds on moderately exposed lower eulittoral rock	Absence	Absence	Absence		
LR_MLR_MusF_MytFves	*Mytilus edulis* and *Fucus vesiculosus* on moderately exposed mid eulittoral rock	Absence	Absence	Absence		
LR_MLR_MusF_MytPid	*Mytilus edulis* and piddocks on eulittoral firm clay	Absence	Absence	Absence		
LS_LBR_LMus_Myt	*Mytilus edulis* beds on littoral sediments	Absence	Absence	Absence		
LS_LBR_LMus_Myt_Mu	*Mytilus edulis* beds on littoral mud	Absence	Absence	Absence		
LS_LBR_LMus_Myt_Mx	*Mytilus edulis* beds on littoral mixed substrata	Absence		Absence		
LS_LBR_LMus_Myt_Sa	*Mytilus edulis* beds on littoral sand	Absence	Absence	Absence		
LS_LMp_LSgr_Znol	*Zostera noltii* beds in littoral muddy sand	Absence	Absence	Absence	Absence	
LS_LMp_Sm	Saltmarsh	Absence	Absence		Absence	
LS_LSa_St_MytFab	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	Absence		Absence		
SS_SBR_SMus_MytSS	*Mytilus edulis* beds on sublittoral sediment			Absence		
SS_SMp_KSwSS	Kelp and seaweed communities on sublittoral sediment			Absence		
SS_SMp_KSwSS_LsacCho	*Laminaria saccharina* and *Chorda filum* on sheltered upper infralittoral muddy sediment			Absence		
SS_SMp_KSwSS_LsacR	*Laminaria saccharina* and red seaweeds on infralittoral sediments			Absence		
SS_SMp_KSwSS_LsacR_CbPb	Red seaweeds and kelps on tide-swept mobile infralittoral cobbles and pebbles	Absence		Absence		
SS_SMp_KSwSS_LsacR_Gv	*Laminaria saccharina* and robust red algae on infralittoral gravel and pebbles	Absence		Absence		
SS_SMp_KSwSS_LsacR_Mu	*Laminaria saccharina* with red and brown seaweeds on lower infralittoral muddy mixed sediment	Absence		Absence		
SS_SMp_KSwSS_LsacR_Sa	*Laminaria saccharina* and filamentous red algae on infralittoral sand			Absence		
SS_SMp_SSgr	Sublittoral seagrass beds		Absence	Absence	Absence	
SS_SMp_SSgr_Zmar	*Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand		Absence	Absence	Absence	
SS_SMx_IMx_Ost	*Ostrea edulis* beds on shallow sublittoral muddy mixed sediment	Absence	Absence	Absence	Absence	
Random points below 30 m	800 random points from waters in NI but below 30 m created in ArcMap		Absence			

Variable selection

Groups of correlated variables (correlations > 0.7) were reduced to one randomly selected variable within said group with hierarchical clustering from the “virtualspecies” package (Leroy, 2016). Some variables were manually imposed or excluded, in the models of some species. The final number of variables in each mode varied from 7 to 14. The exact list of variables used and imposed in each model is in Table 5.

Table 5. List of predictor variables used in each model.

Variable	*Laminaria digitata*	*Laminaria hyperborea*	*Mytilus edulis*	*Ostrea edulis*	*Saccharina latissima*	Saltmarsh	*Zostera marina*	*Zostera noltei*
Aspect	X	X	X	X	X	X	X	X
Bathymetry	X	X	X	X	X	X	X	X
Coastal Erosion	_	_	_	_	_	X	_	_
Current	X	X	X	X	X	_	X	X
Curvature planform	X	X	X	X	X	X	X	X
Curvature profile	_	X	X	X	X	_	_	X
Curvature total	X	_	_	_	_	X	X	_
Distance to Mussels farms	_	_	X	_	_	_	_	_
Distance to Oyster farms	_	_	_	X	_	_	_	_
Hard/soft substrate	X	X	X	X	X	X	X	X
Maximum Temperature	X	_	_	_	_	_	_	_
Mean Temperature	X	X	X	X	X	_	X	X
Minimum Temperature	_	X	X	_	_	_	_	_
Nitrates concentration	X	X	_	_	X	_	X	X
PAR at Seabed	X	X	_	_	X	_	X	X
Roughness or rugosity	_	_	_	_	X	_	_	_
Salinity	X	X	_	X	X	_	X	X
Slope	X	X	X	X	_	X	X	X
Temperature in Spring	_	_	_	X	_	_	_	X
Temperature in Summer	_	_	X	_	X	_	X	_
Substrate category	X	X	X	X	X	_	X	X
Wave kinetic energy	X	X	X	X	X	_	X	X

HS model training, prediction and validation

The HS modelling used a machine learning technique called a Random Forest (Breiman, 2001) and were implemented in R. The models used the 'predict.ranger.forest' function from the "*ranger*" package (Wright *et al*, 2018) using the default settings and the regression model selected (i.e. the output of the model will be 0 to 1 rather than 0 or 1 for a classifier). The same models were used to generate: (i) HS predictions on a 0 – 1 scale; (ii) model performance statistics (out-of-bag (OOB) error and R-squared) and confidence surfaces (agreement between each iteration of the model / consistency of the predictions among the trees); and (iii) the Environmental value ranges for medium and high habitat suitability with partial dependence plots obtained with the “pdp” package in R (Greenwell, 2017). The R code for the modelling process has been provided in the Appendix of this report.

The raster output from R was then imported to ArcMap. HS rasters were classified using the ‘reclassify’ tool into areas of medium and high suitability (thresholds can be found in Table 7) before being converted into polygons – an ArcMap ‘Blue Carbon’ toolbox, containing model builder files, has been provided with the ArcMap project so that the processing steps can be repeated at any time. Due to the lack of absence data for saltmarsh at elevations above the typical habitat (i.e. terrestrial absence points), an analysis mask was used to restrict predictions to between 0 and 10 m elevation only.

Each species and habitat were attributed with their ‘Net Primary Productivity’ (NPP) to reflect their value as carbon fixers and ‘Carbon Sequestration Rate’ (CSR) to capture their value for facilitating carbon storage. The NPP and CRS values were obtained from the literature and can be found in Table 6. To understand the potential spatial distribution of both processes, the NPP and CSR for each species was scaled by the HS score, i.e. maximum NPP was only achieved in areas with HS scores near 1. The scaled NPP and CSR values were then summed across all species using raster calculator in ArcMap. The scaled and summed NPP and CSR were then multiplied together to highlight potential overlap areas (between BC sources and sinks) and potential BC hotspots.

Table 6. Literature values for the Net Primary Productivity and Carbon Sequestration Rate for all species and habitats.

	Net Primary Productivity **(g C m 2 yr)**	**Sequestration rate** **(g C m 2 yr)**	**References**
Laminaria hyperborea	340	0	Observations from across the UK and considered suitable for use for Northern Irish populations. Values reported here are from the nearest station to Northern Ireland (west coast of Scotland).
Laminaria digitata	344	0	Observations from across the UK and considered suitable for use for Northern Irish populations. Values reported here are from the nearest station to Northern Ireland (west coast of Scotland).
Ostrea edulis	0	50[31]	Values based on 75 ind/ m2, which is significantly greater than the natural density of O. edulis. The values reported here are considered an over-estimation of local rates.
Mytilus edulis	0	81	Observations of mussels from Vrdngskar (Baltic). The reported value is a mean of several seasonal measurements and is considered suitable for use for Northern Irish populations.
Saccharina latissima	577	0	In situ observations from Rhode Island USA. The reported value s here are considered moderately suitable for Northern Irish populations.
Saltmarsh	278[32]	266	Meta-data mean based on 174 reviews, 414 papers and 56 book chapters. The values report here are considered a suitable average for saltmarsh in Northern Ireland.
Zostera marina	295	226	The same values were used for a similar study in Scotland. The values reported here are considered to be moderately suitable for use with Northern Irish populations.

Mapping extent

Mapping the extent of each feature used a simple but safe approach. Presence data were buffered by 480 m using the buffer tool in ArcMap. This buffer distance was selected by eye as a suitable

[31] Based on 75 individuals m^2 from Lee et al. (2020) and therefore a very high density.
[32] Based on the Net Ecosystem Productivity (NEP), i.e. based on the total NPP of all species in this habitat – taken from Alongi (2020).

value to coalesce localised clusters of points without extrapolating the extent excessively. The buffered area was then clipped using the outputs of the HS model (clipped using the medium habitat suitability). The resulting extent polygons are therefore constrained to suitable habitat as well as being based on actual occurrence observations.

Value range for suitable habitat

To understand how each individual predictor affect the predictions of the models, partial dependence was used to visualise the range of said parameter values corresponding to medium and high suitability for each species. A derivative of partial dependence plots, termed 'Individual Conditional Expectation' (ICE) curves (Goldstein et al., 2015), were calculated for each predictor retained for each species. The minimum, mean (with standard deviation) and maximum predictor values yielding model outputs for medium and high suitability thresholds were extracted from each of these curves. This analysis was conducted with the "pdp" package in R (Greenwell, 2017).

Results

Estimation of Extent and Habitat Suitability

The following sections will present results on: (i) the estimated current extent of species and habitats; (ii) medium and high habitat suitability for each species and habitat; (iii) areas of extent and suitable habitat as well as the environmental conditions within suitable habitat; (iv) spatial estimates of map confidence and OOB statistics; and (v) merged maps of NPP, CSR and potential BC hotspots.

Estimation of current extent

The estimated extent of the species and habitats is based on data from 1980 to 2020. The estimate extent is therefore a reflection of occupation over this period of time. It is possible that some locations, recorded early in this period, are no longer occupied. However, it is assumed that most points remain occupied and relevant for the estimation of extent. The extents provided below have been clipped by the area considered to have a medium or higher habitat suitability for that species. This clip removes buffered areas that fall in unsuitable habitat (e.g. seagrass areas above the high-water level etc.) – this approach was also used in Strong et al. (2016) for *Modiolus modiolus* in Strangford Lough. The estimated current extent for *Z. marina* (Figure 4), *Z. noltei* (Figure 5), saltmarsh (Figure 6), *L. digitata* (Figure 7), *L. hyperborea* (Figure 8), *S. latissima* (Figure 9), *M. edulis* (Figure 10) and *O. edulis* (Figure 11) are provided below.

It is apparent that a high proportion of the extent of *Z. marina*, *Z. noltei*, saltmarsh, *M. edulis* and *O. edulis* occurs within the sea loughs. Both *L. digitata* and *L. hyperborea* are extensively distributed along the open coast. *S. latissima* appears to prefer more sheltered waters and occurs both along the open coastline and in the sea loughs.

Based on the area of each extent, it is apparent that *O. edulis* and *S. latissima* occupy the greatest area (Table 7). *L. digitata* and *L. hyperborea* occupy both similar distributions and total areas. The two *Zostera* species occupy the smallest area. It is important to note that the extent is based on presence only and should not be taken as a reflection on the condition of the sub-populations within patches. Equally, it is likely that the buffer value may over-estimate the extent of rare species that have very localised and heterogeneous distributions (e.g. *Z. marina* and *Z. noltei*).

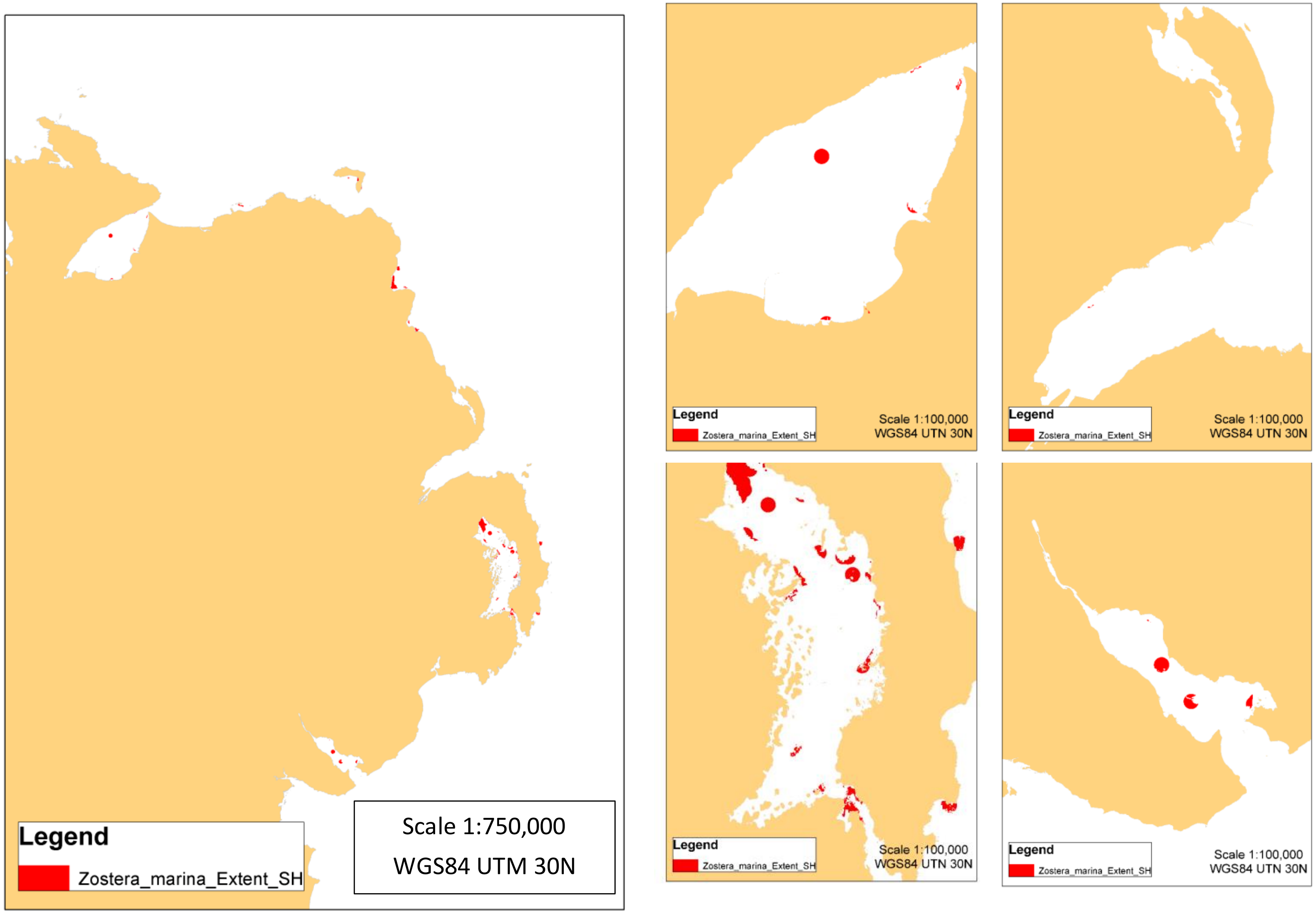


Figure 4. Current estimated extent (red) of Zostera marina in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

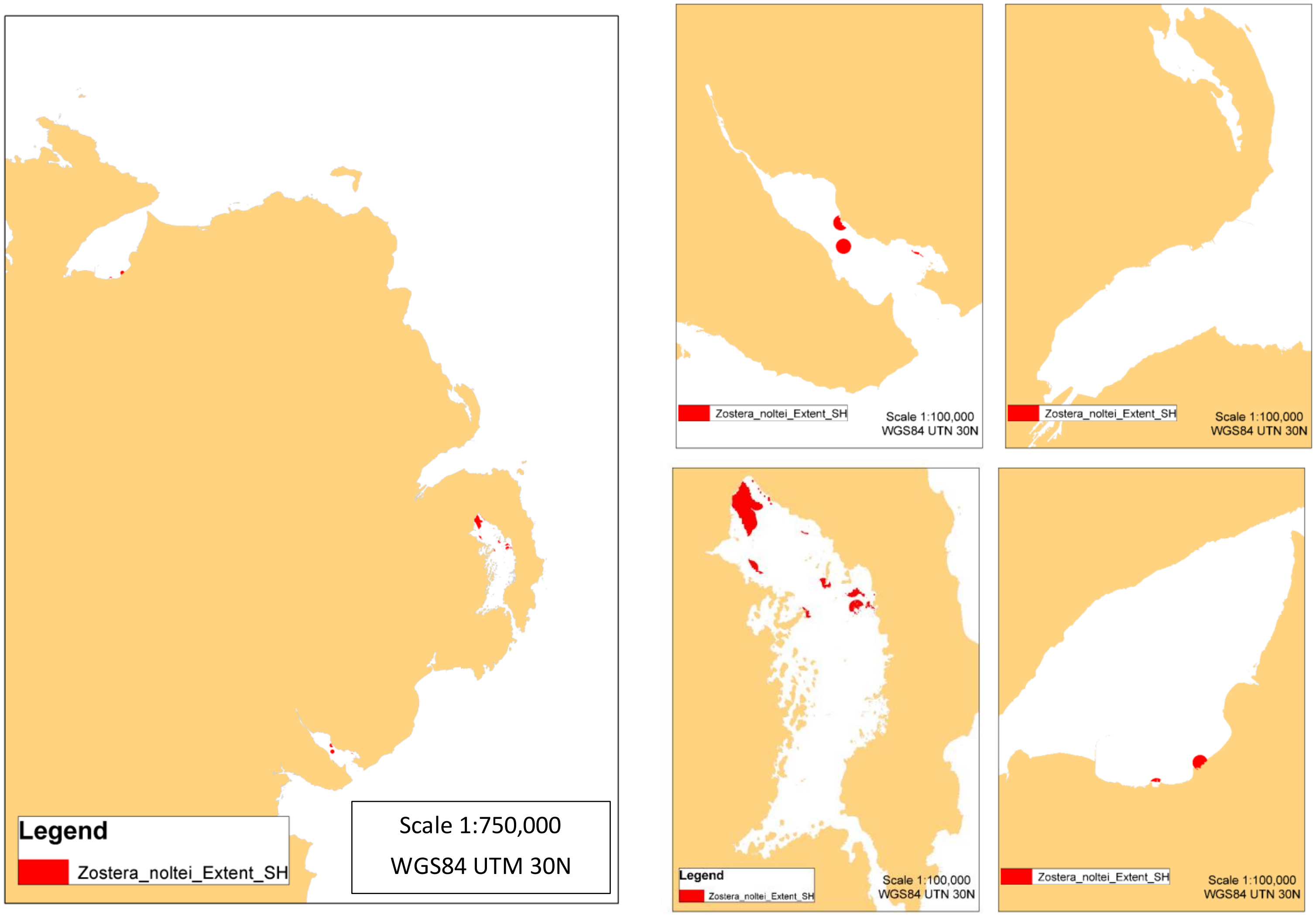


Figure 5. Current estimated extent (red) of Zostera noltei in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

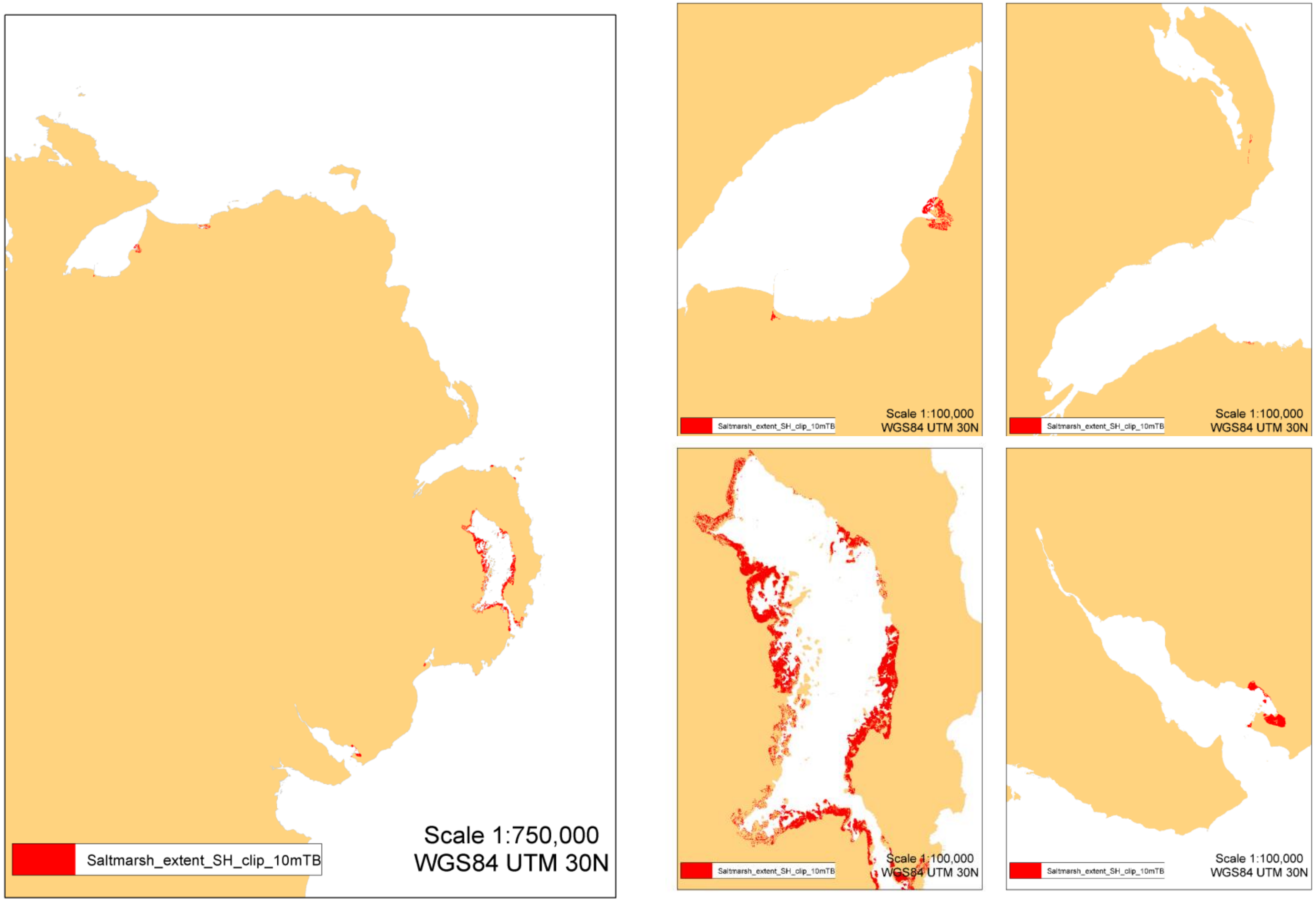


Figure 6. Current estimated extent (red) of saltmarsh in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

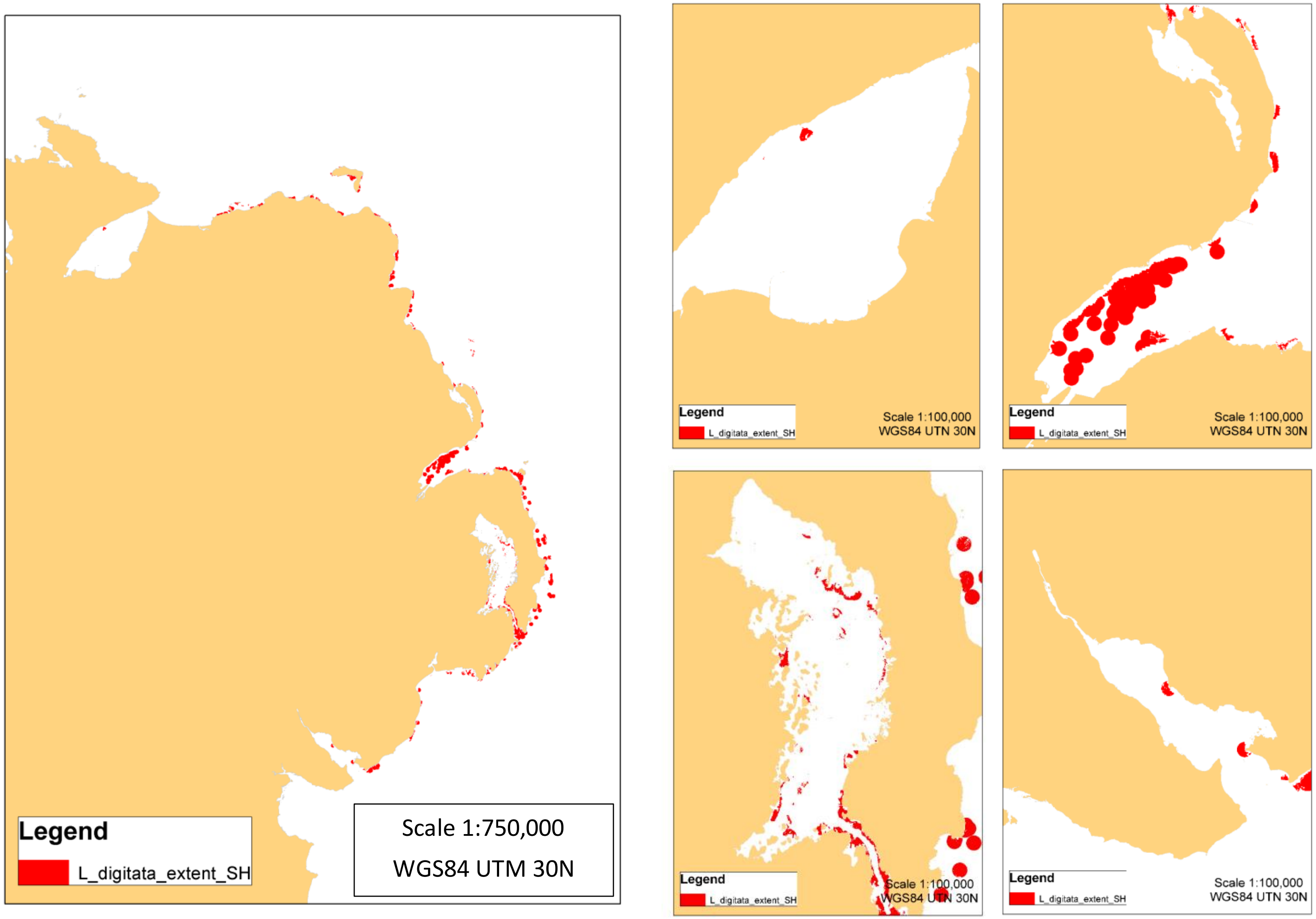


Figure 7. Current estimated extent (red) of Laminaria digitata in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

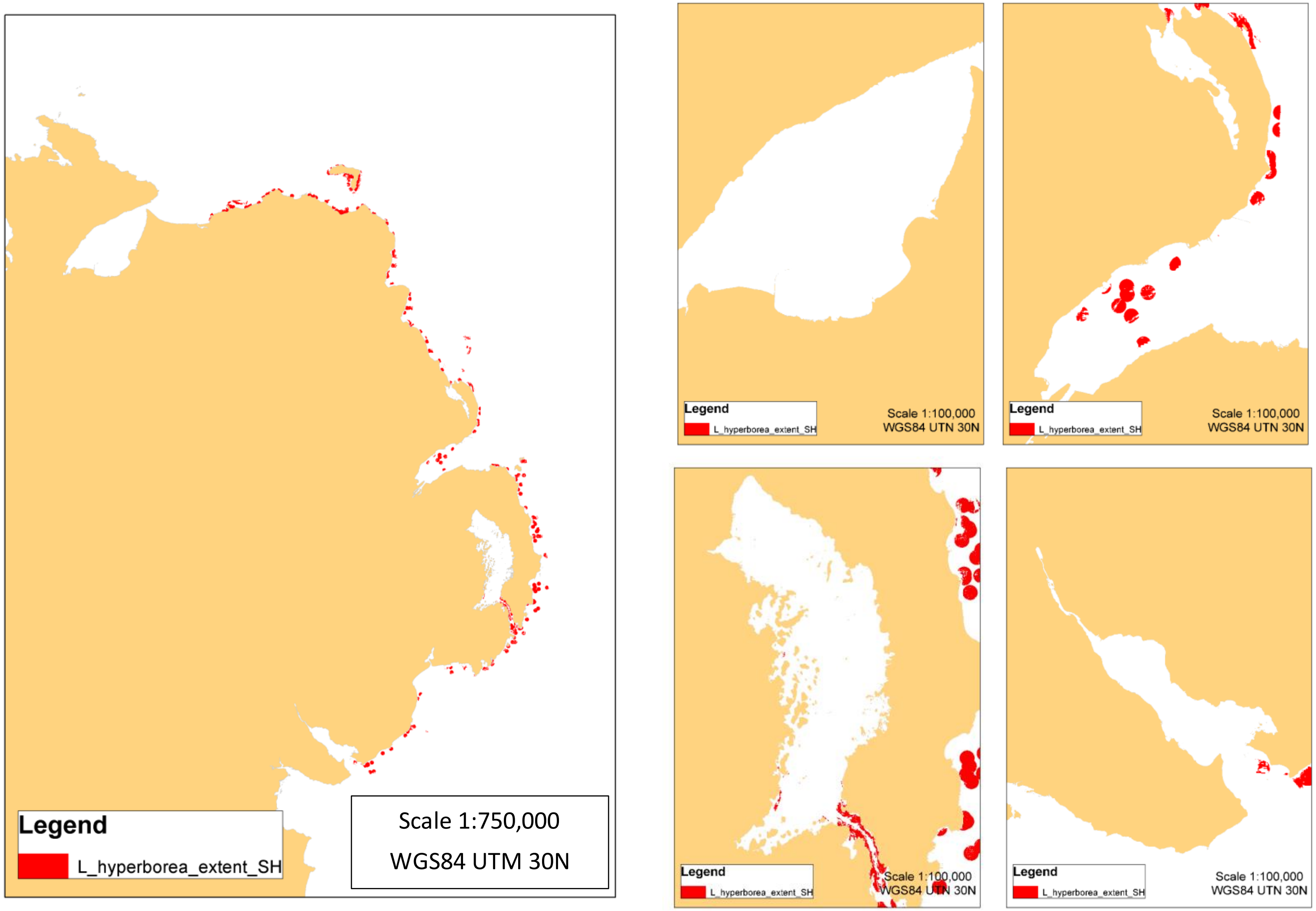


Figure 8. Current estimated extent (red) of Laminaria hyperborea in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

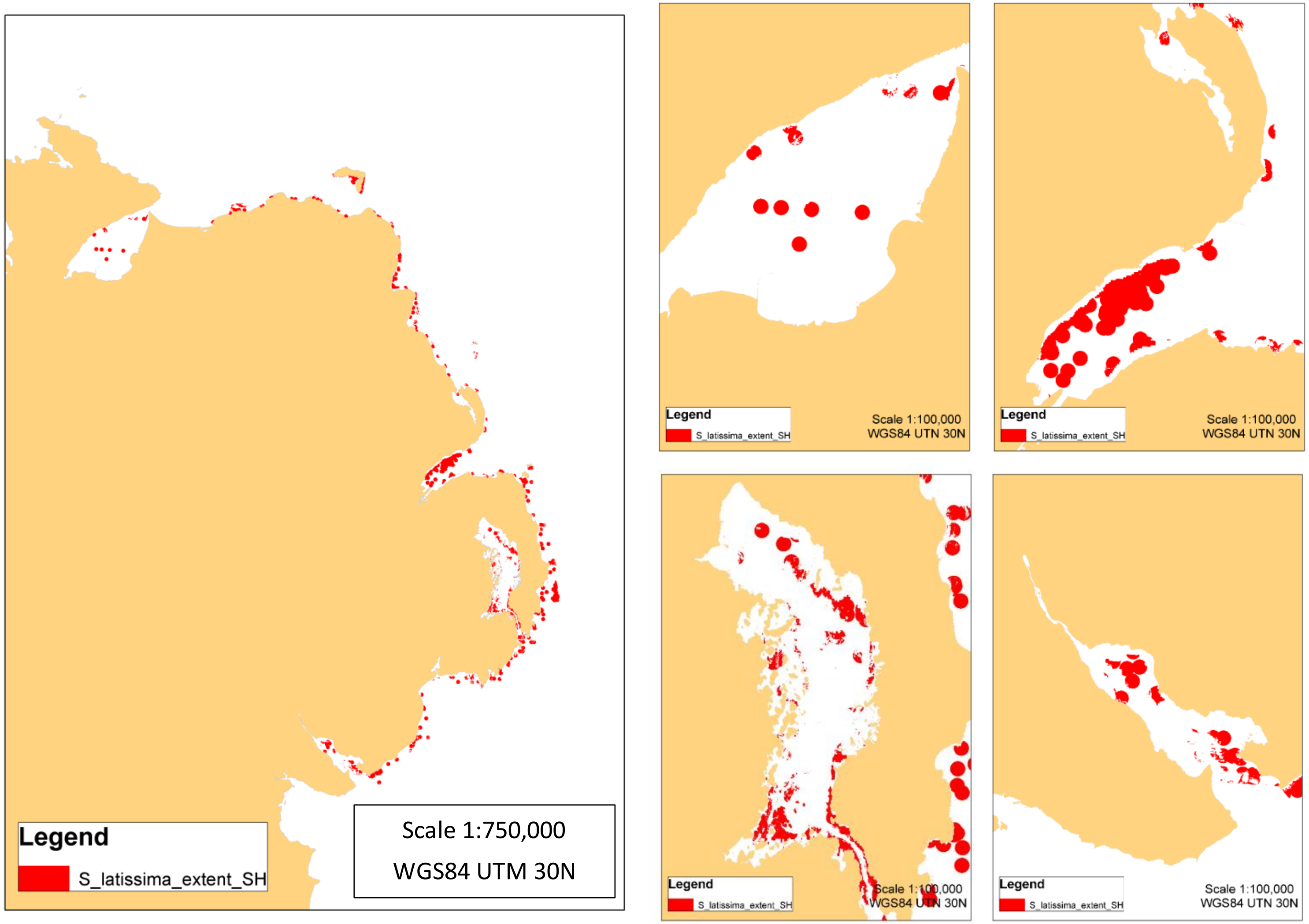


Figure 9. Current estimated extent (red) of Saccharina latissima in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

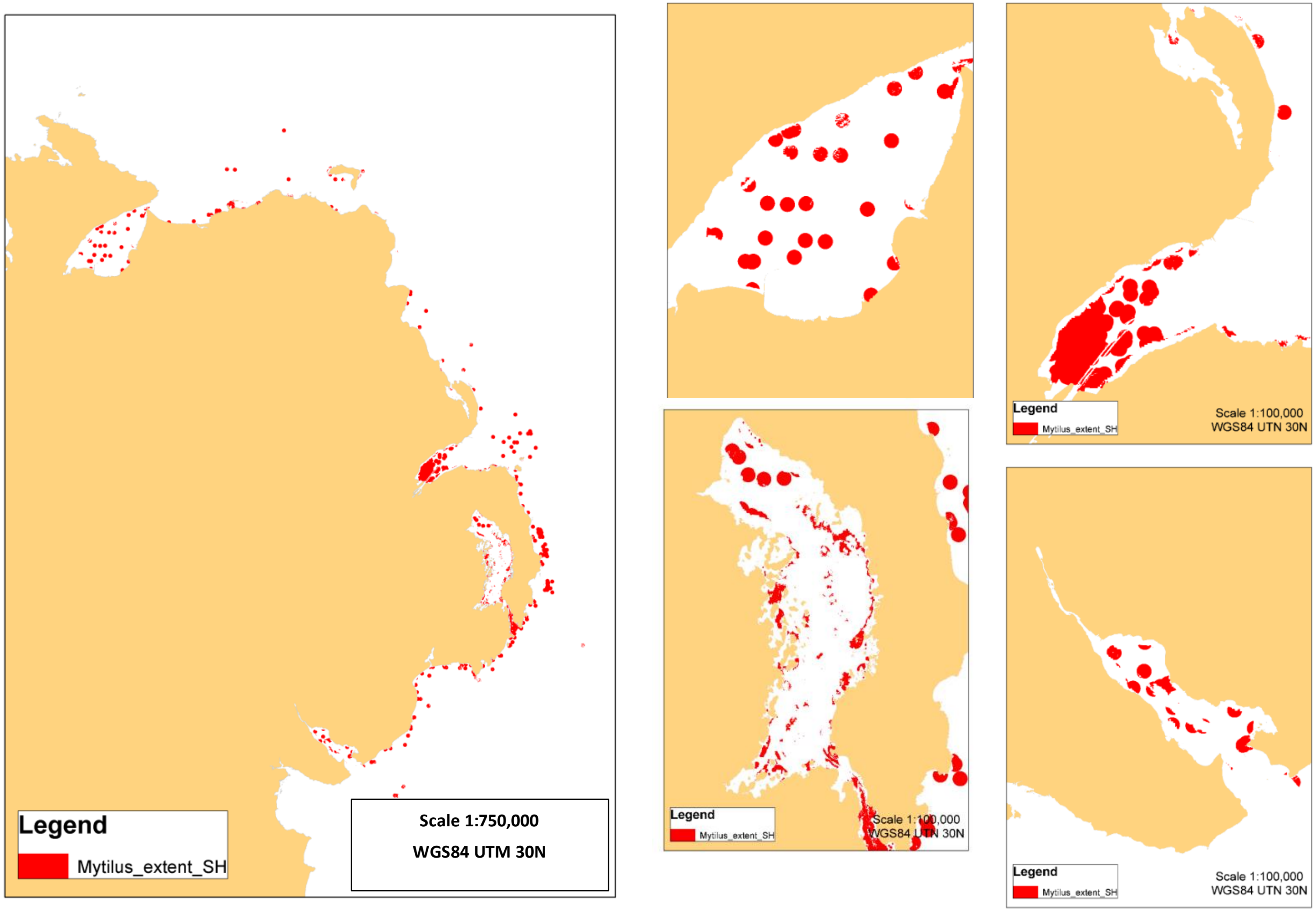


Figure 10. Current estimated extent (red) of Mytilus edulis in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

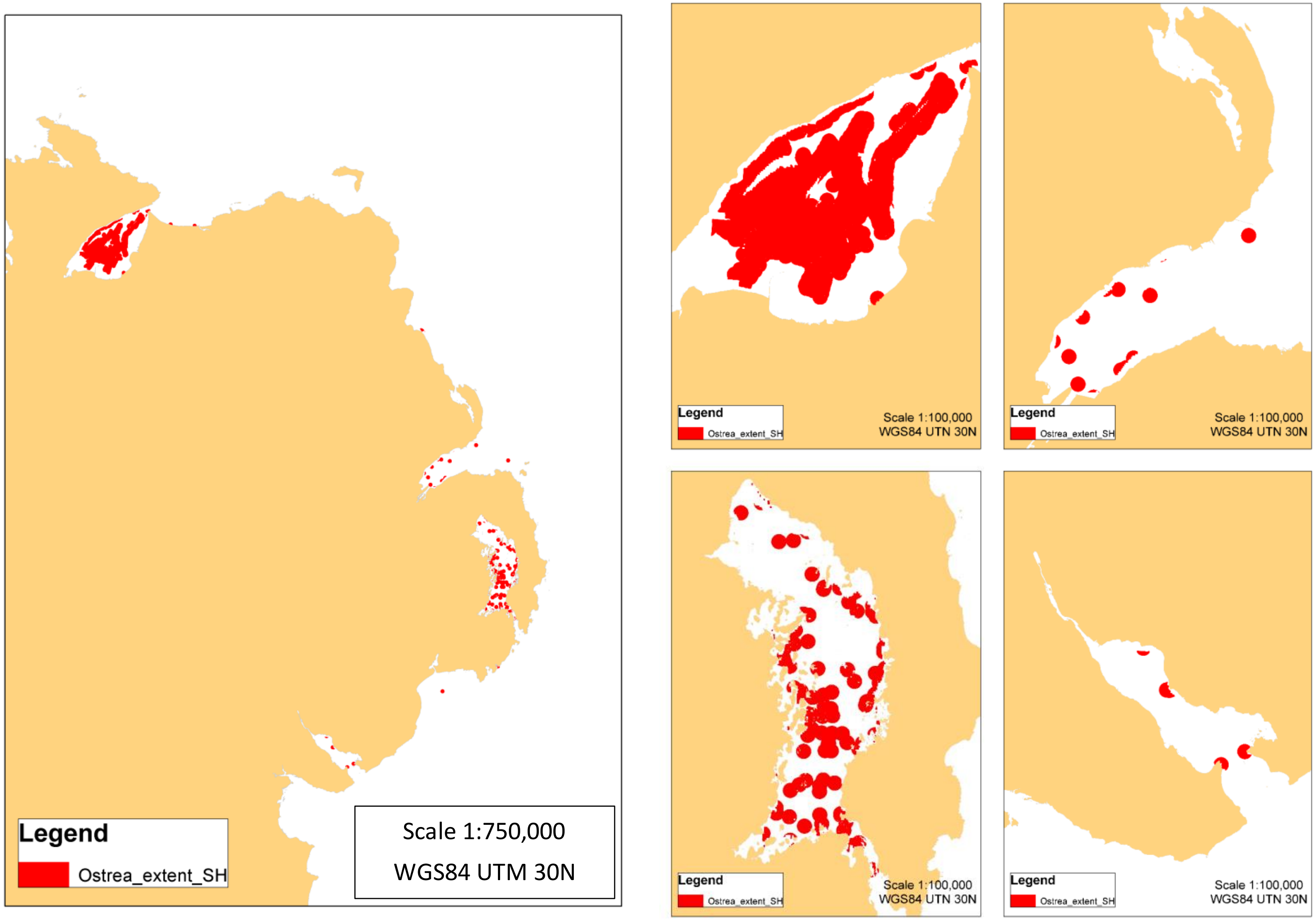


Figure 11. Current estimated extent (red) of Ostrea edulis in Northern Ireland (based on information from 1980 – 2020). The projection is UTM (not UTN) Zone 30 North for sea lough maps.

Table 7. The area of current extent, medium habitat suitability (with threshold), high habitat suitability (with threshold) for all species and habitats considered.

Species or habitat	Extent area (km^2)	High suitability threshold	High suitability area (km^2)	Medium suitability threshold	Medium suitability area (km^2)
Laminaria hyperborea	82.2	0.90	97.0	0.80	165.4
Laminaria digitata	83.7	0.90	122.9	0.80	182.5
Ostrea edulis	167.9	0.90	486.3	0.80	809.6
Mytilus edulis	140.2	0.90	878.5	0.80	1861.5
Saccharina latissima	136.0	0.90	290.4	0.80	264.6
Saltmarsh	31.1	0.75	13.7	0.50	90.8
Zostera marina	15.8	0.75	87.3	0.50	171.6
Zostera noltei	1.4	0.75	127.5	0.50	49.1

Habitat suitability (medium and high suitability)

The predicted distribution of medium and high habitat suitability *Z. marina* (Figure 12), *Z. noltei* (Figure 13), saltmarsh (Figure 14), *L. digitata* (Figure 15), *L. hyperborea* (Figure 16), *S. latissima* (Figure 17), *M. edulis* (Figure 18) and *O. edulis* (Figure 19) are provided below.

As per the estimates of extent, a high proportion of the suitable habitat for *Z. marina*, *Z. noltei*, saltmarsh, *M. edulis* and *O. edulis* occurs within the sea loughs. The HS maps predict large amounts of suitable habitat subtidally but it is recognised that many subtidal areas cannot persist without sustained aquaculture practices. Suitable habitat for both *L. digitata* and *L. hyperborea* is extensively distributed along the open coast. The preference of *S. latissima* for sheltered waters places suitable habitat both along the open coastline (e.g. Ards Peninsula) and in all of the sea loughs.

Based on the area of suitable habitat for each feature, it is apparent that *O. edulis* and *S. latissima* occupy the greatest area (Table 7). *L. digitata* and *L. hyperborea* occupy both similar distributions and total areas. The two *Zostera* species occupy the smallest area. It is important to note that the extent is based on presence only and should not be taken as a reflection on the condition of the sub-populations within patches. Equally, it is likely that the buffer value may over-estimate the extent of rare species that have very localised and heterogeneous distributions (e.g. *Z. marina* and *Z. noltei*).

Confidence layers

The R^2 value relates to the amount of variance explained and the closer the value to one the better. The R^2 value is calculated using the OOB data (bootstrapped observations set aside and not used in an iteration of the model). The OOB error rate is also derived from the OOB data.

The high R^2 values for the two seagrass models (Figure 20), three kelp models (Figure 21) and *O. edulis* model (Figure 22) suggest high predictive performance and that the resulting models explain a high proportion of the variance within the training dataset. The *M. edulis* model explains just over half of the variance and suggests a moderate level of model performance (Figure 22). The saltmarsh model has a lower R^2 value and indicates that the model is under-performing (Figure 20), probably due to the lack of PVs and the heavy use of interpolation to get subtidal PV higher up the shore.

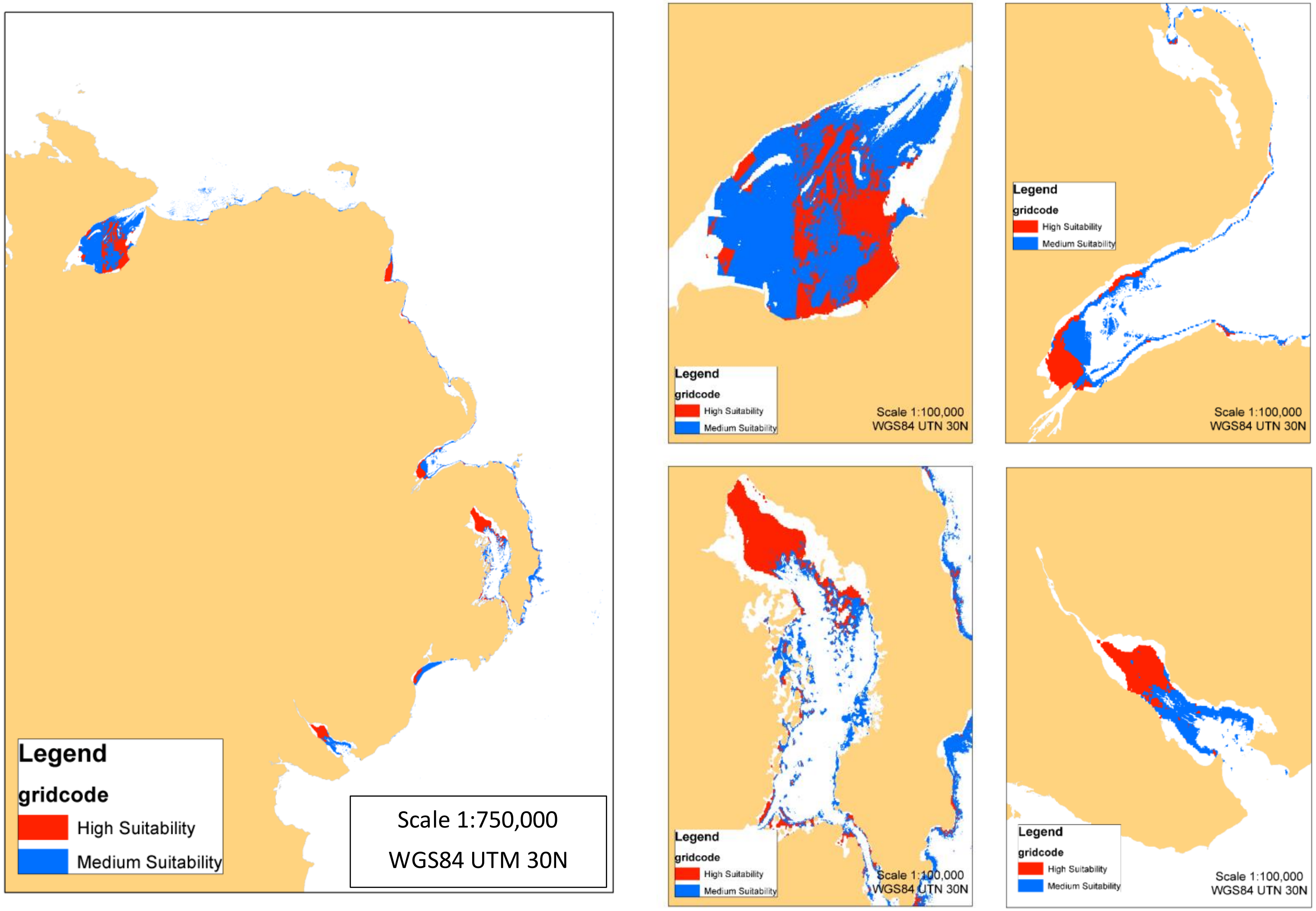


Figure 12. Predicted distribution of medium and high habitat suitability for Zostera marina in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

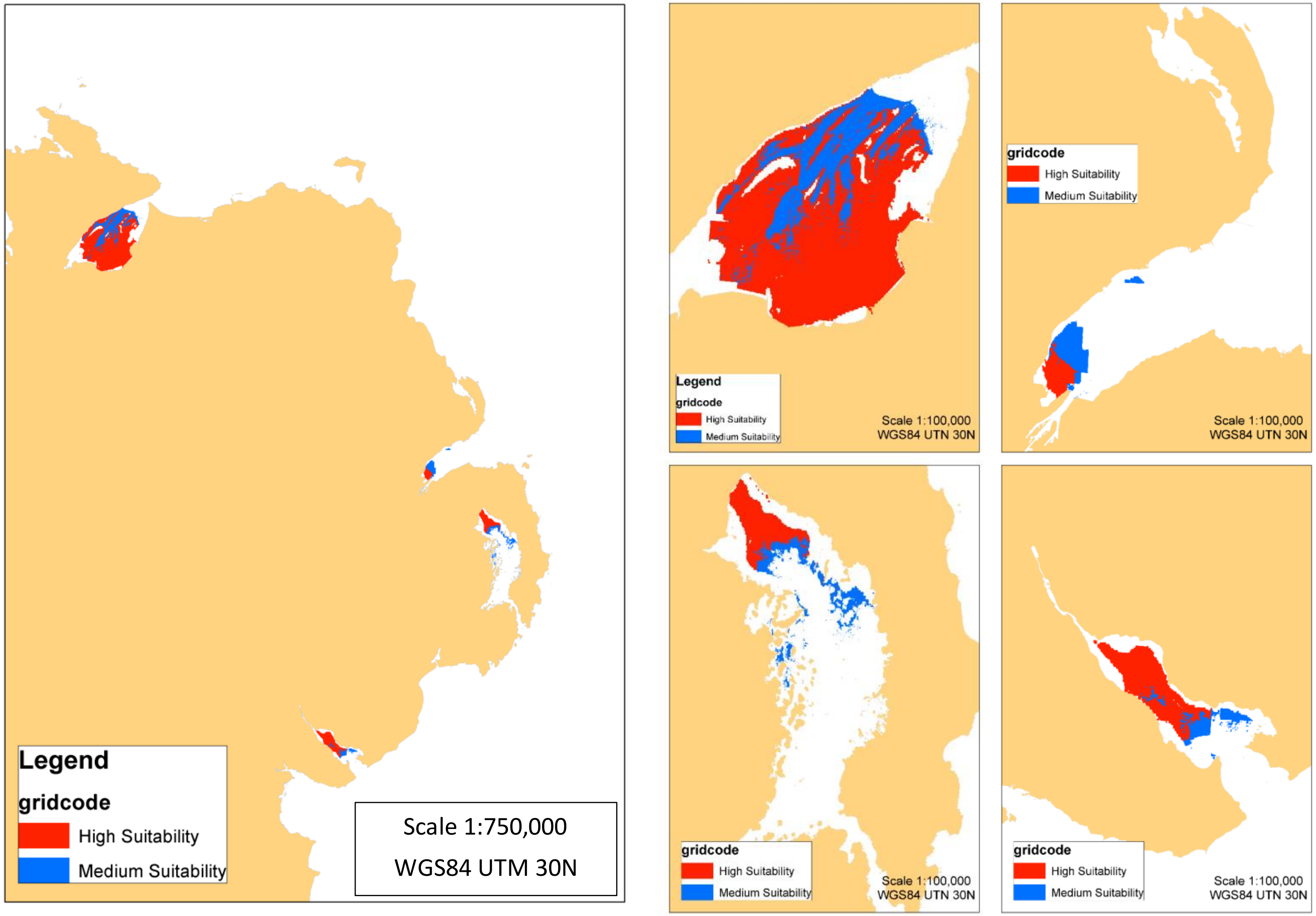


Figure 13. Predicted distribution of medium and high habitat suitability for Zostera noltei in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

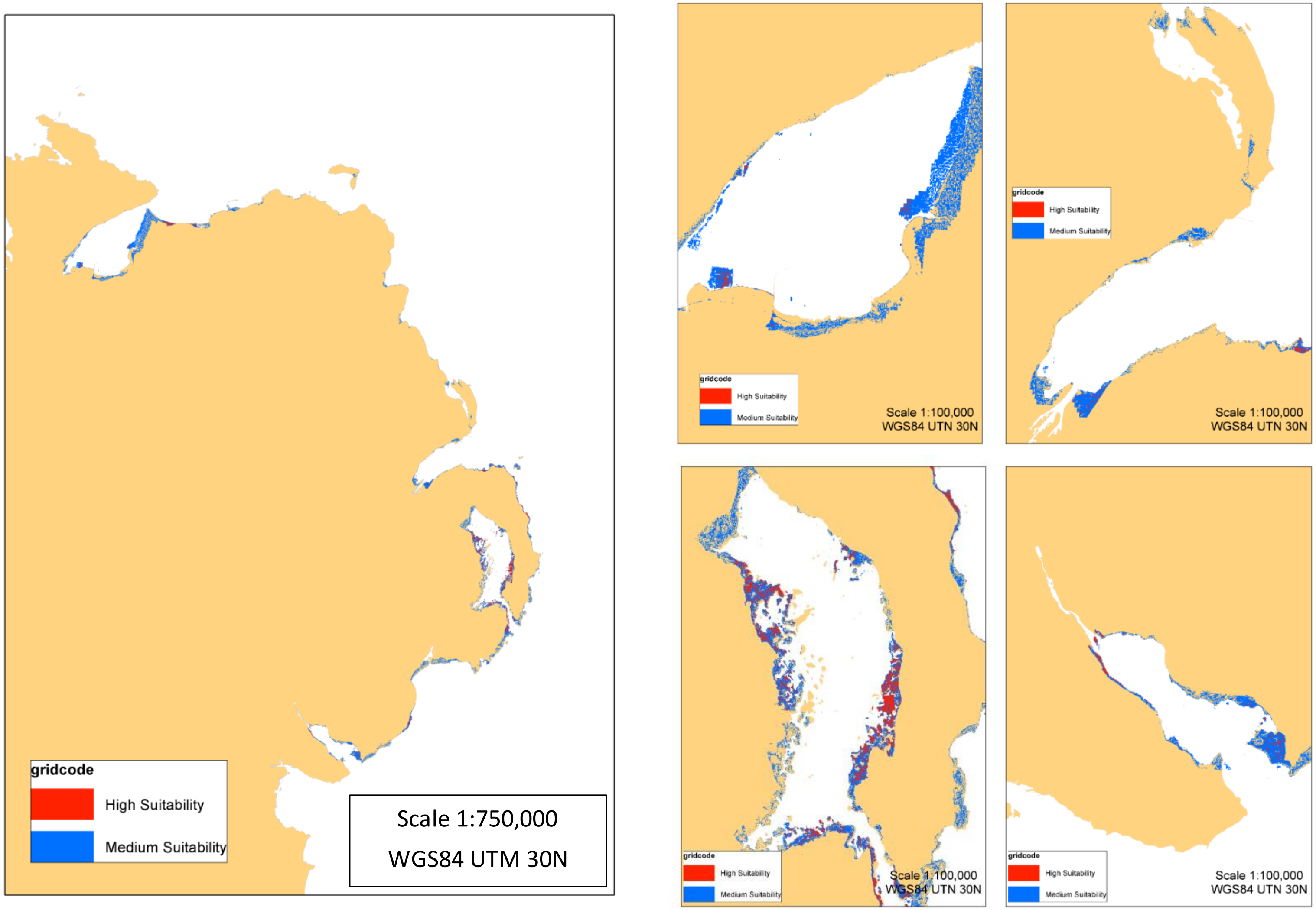


Figure 14. Predicted distribution of medium and high habitat suitability for saltmarsh in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

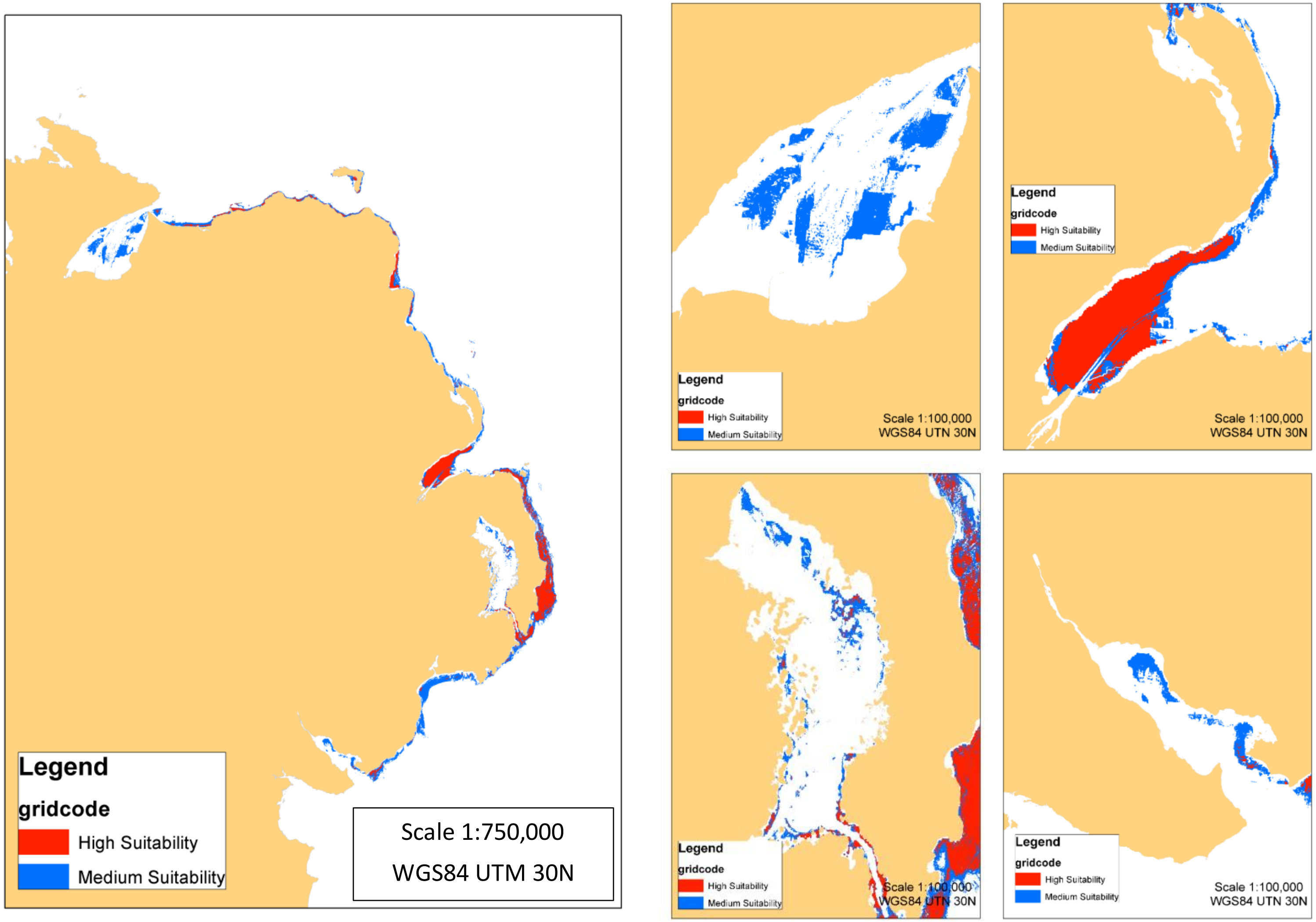


Figure 15. Predicted distribution of medium and high habitat suitability for Laminaria digitata in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

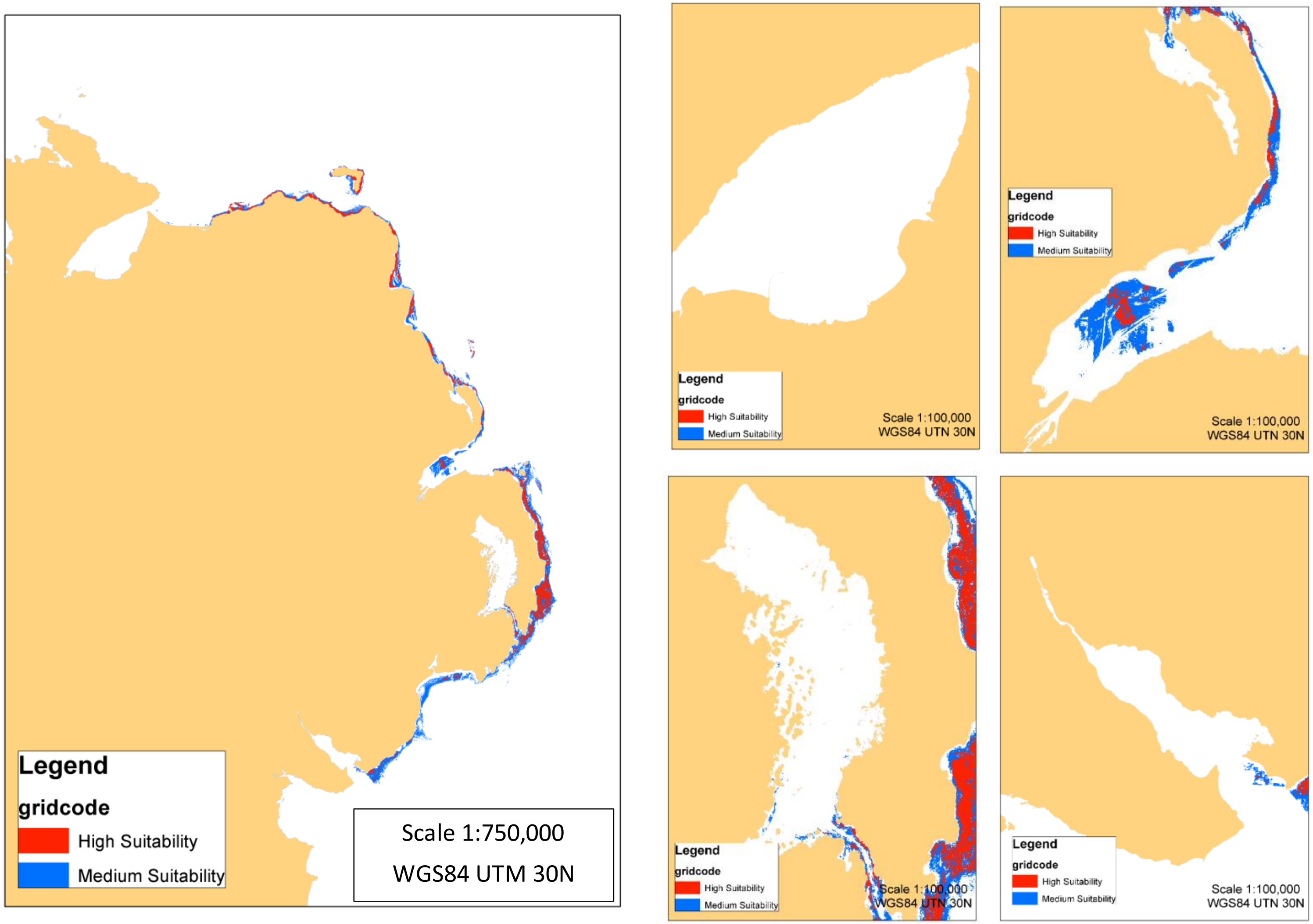


Figure 16. Predicted distribution of medium and high habitat suitability for Laminaria hyperborea in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

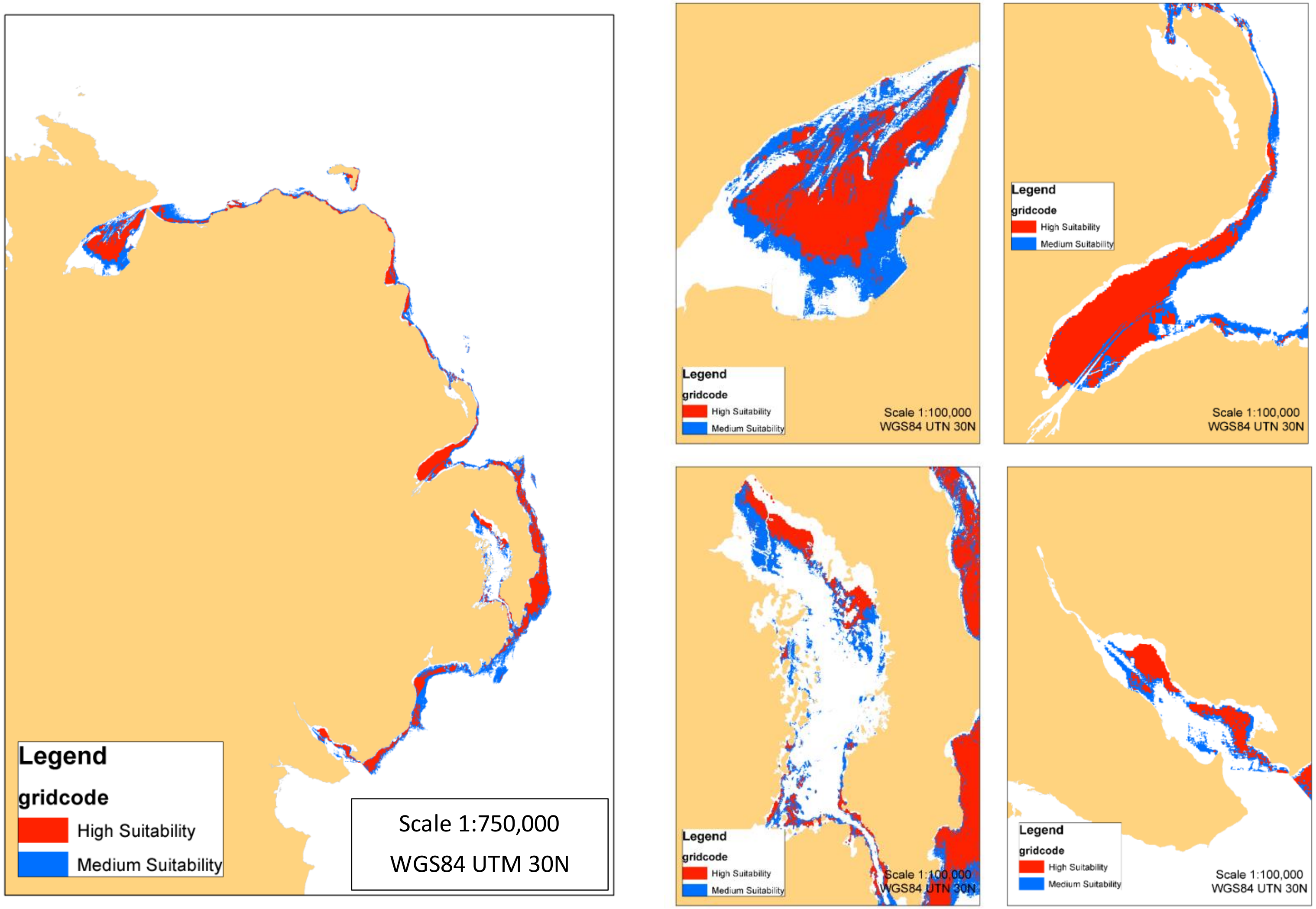


Figure 17. Predicted distribution of medium and high habitat suitability for Saccharina latissima in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

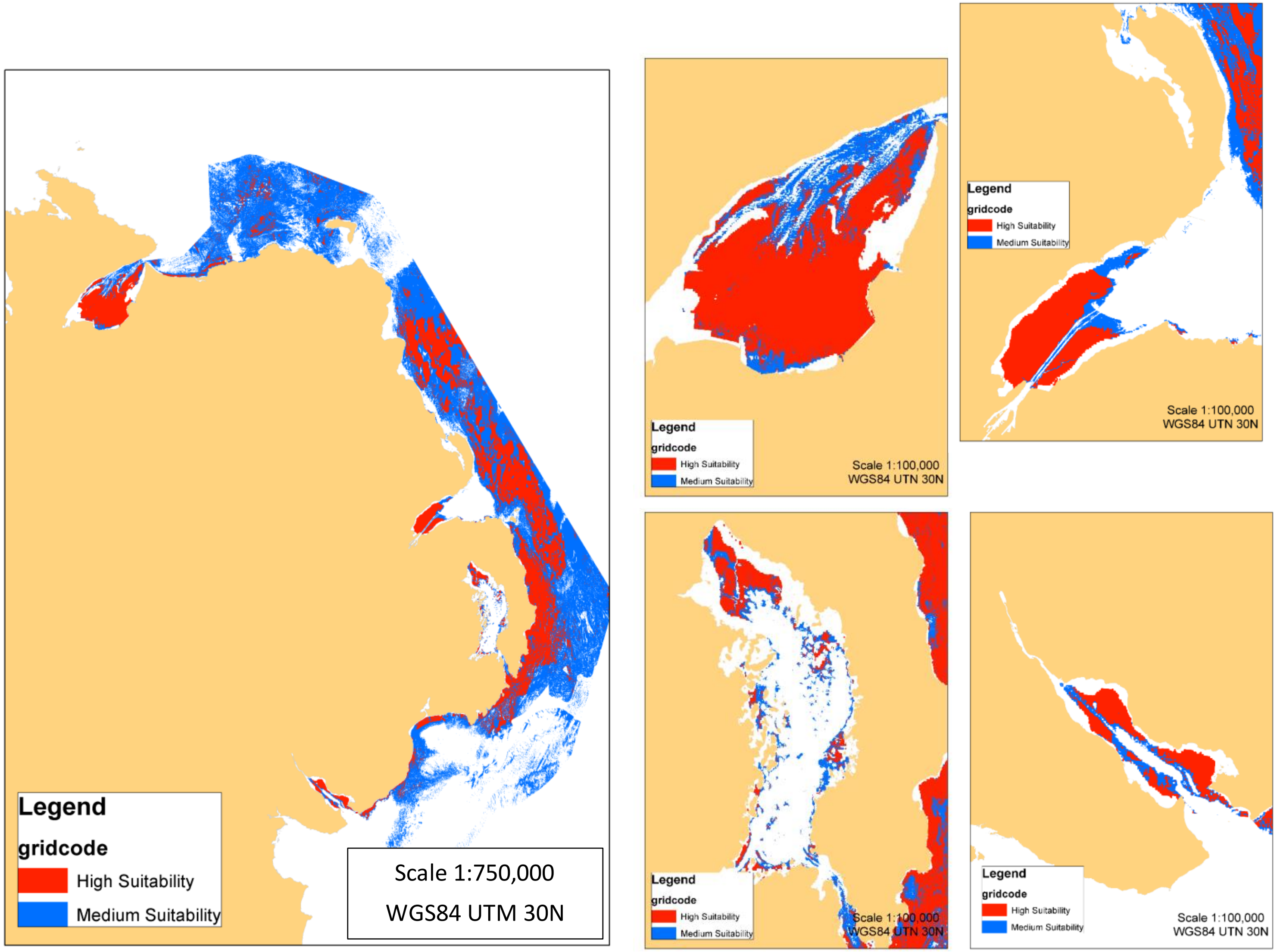


Figure 18. Predicted distribution of medium and high habitat suitability for Mytilus eduils in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

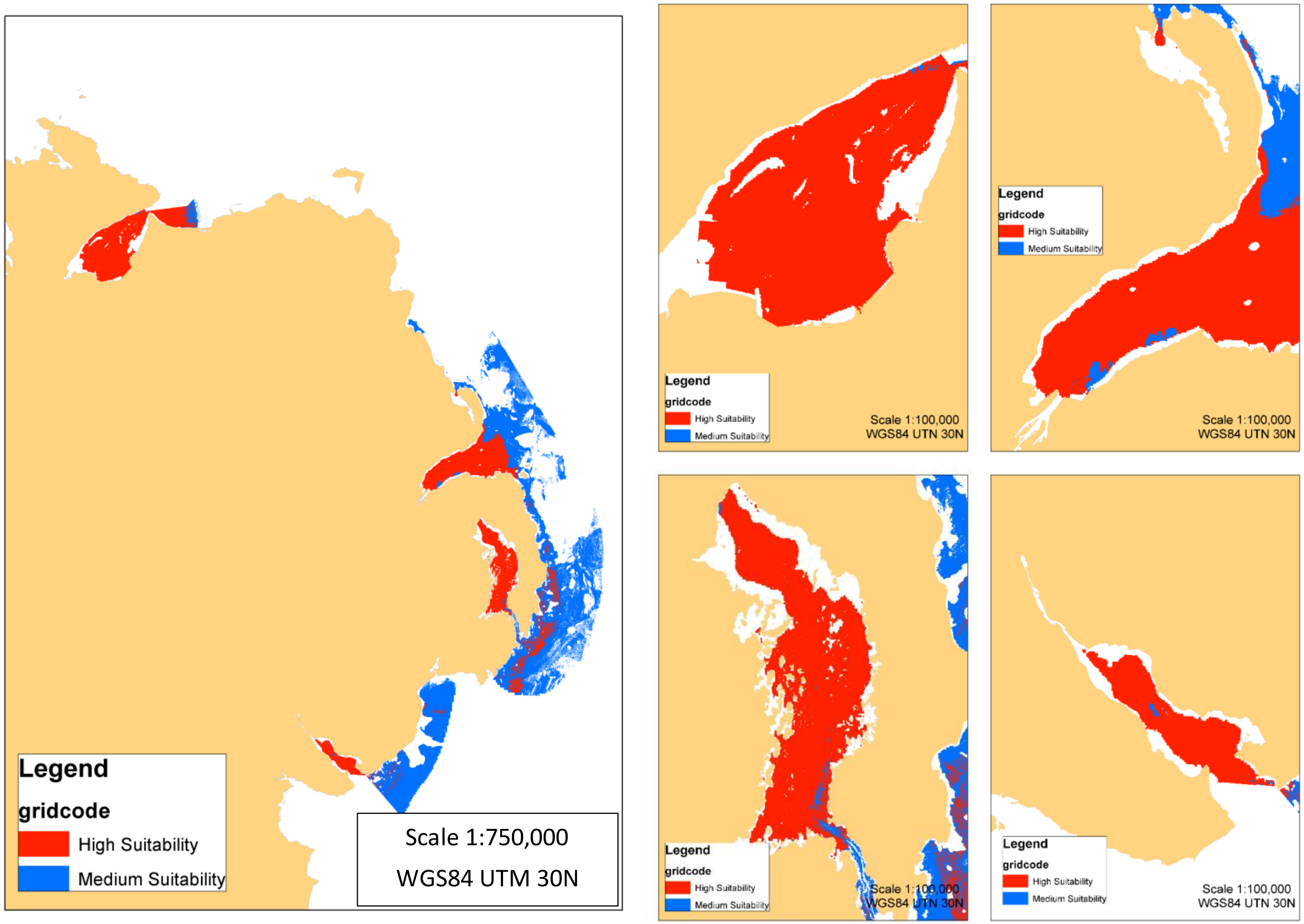


Figure 19. Predicted distribution of medium and high habitat suitability for Ostrea edulis in Northern Ireland. The projection is UTM (not UTN) Zone 30 North for sea lough maps.

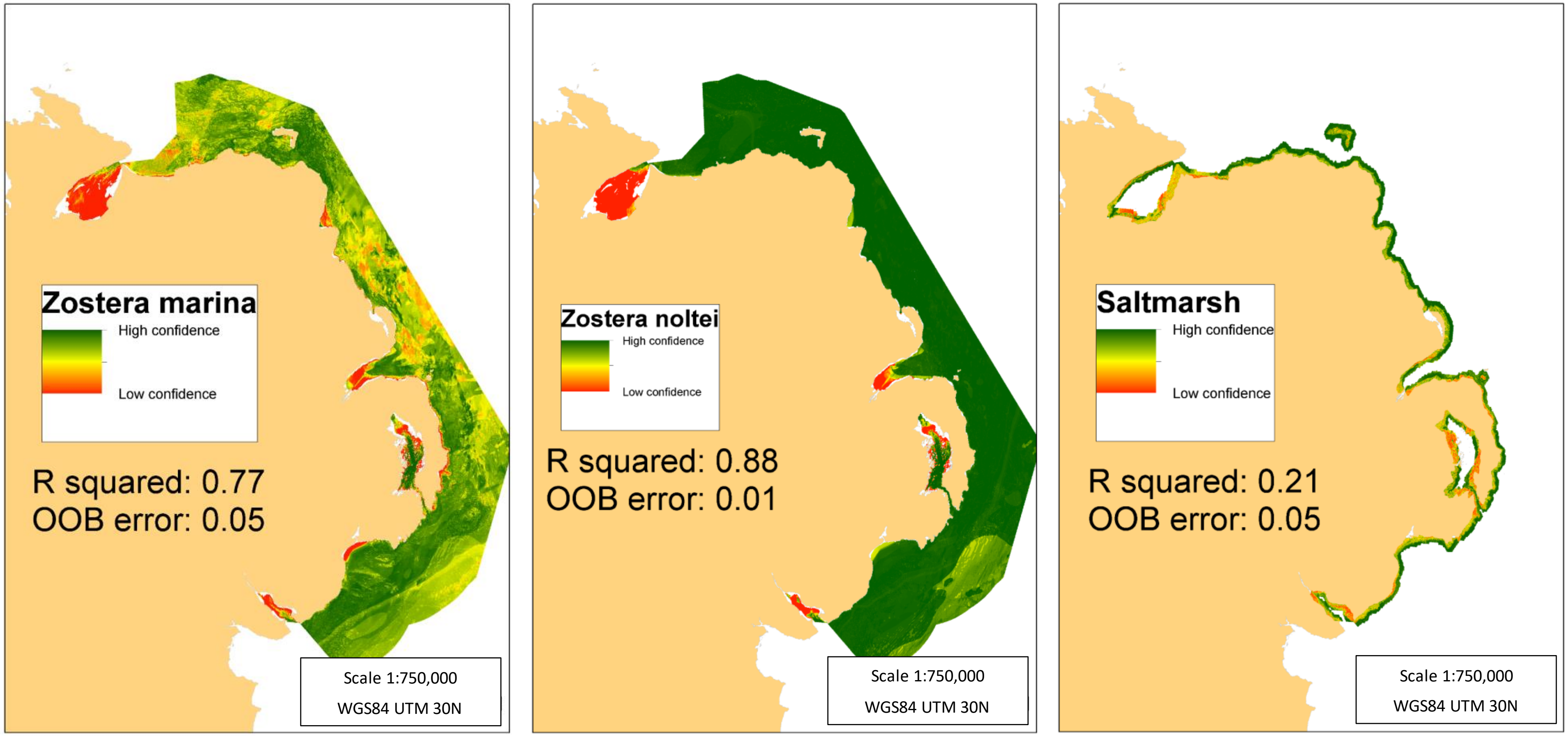


Figure 20. Model performance statistics and spatial confidence layer for Zostera marina (left), Z. noltei (middle) and saltmarsh (right).

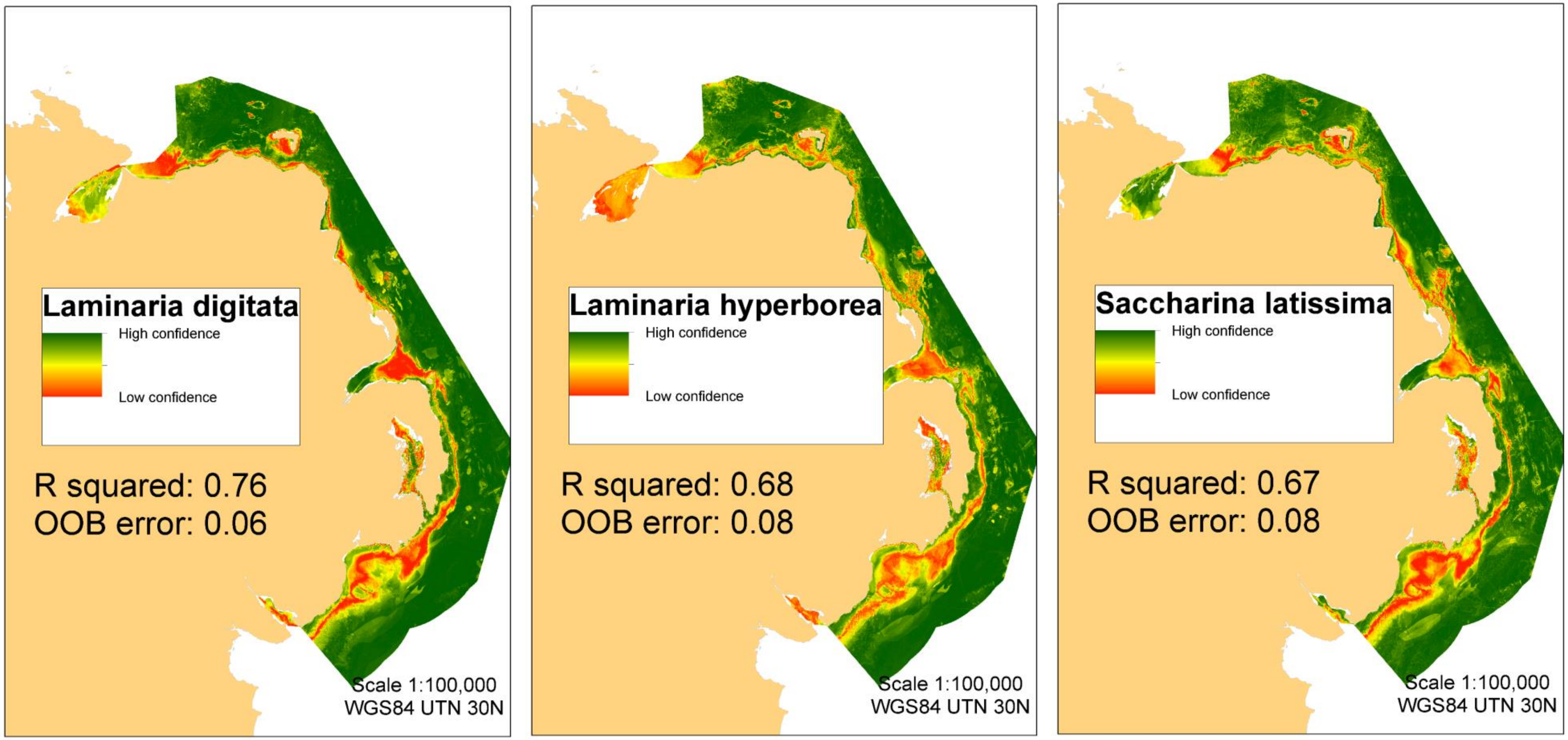


Figure 21. Model performance statistics and spatial confidence layer for Laminaria digitata (left), L. hyperborea (middle) and Saccharina latissima (right).

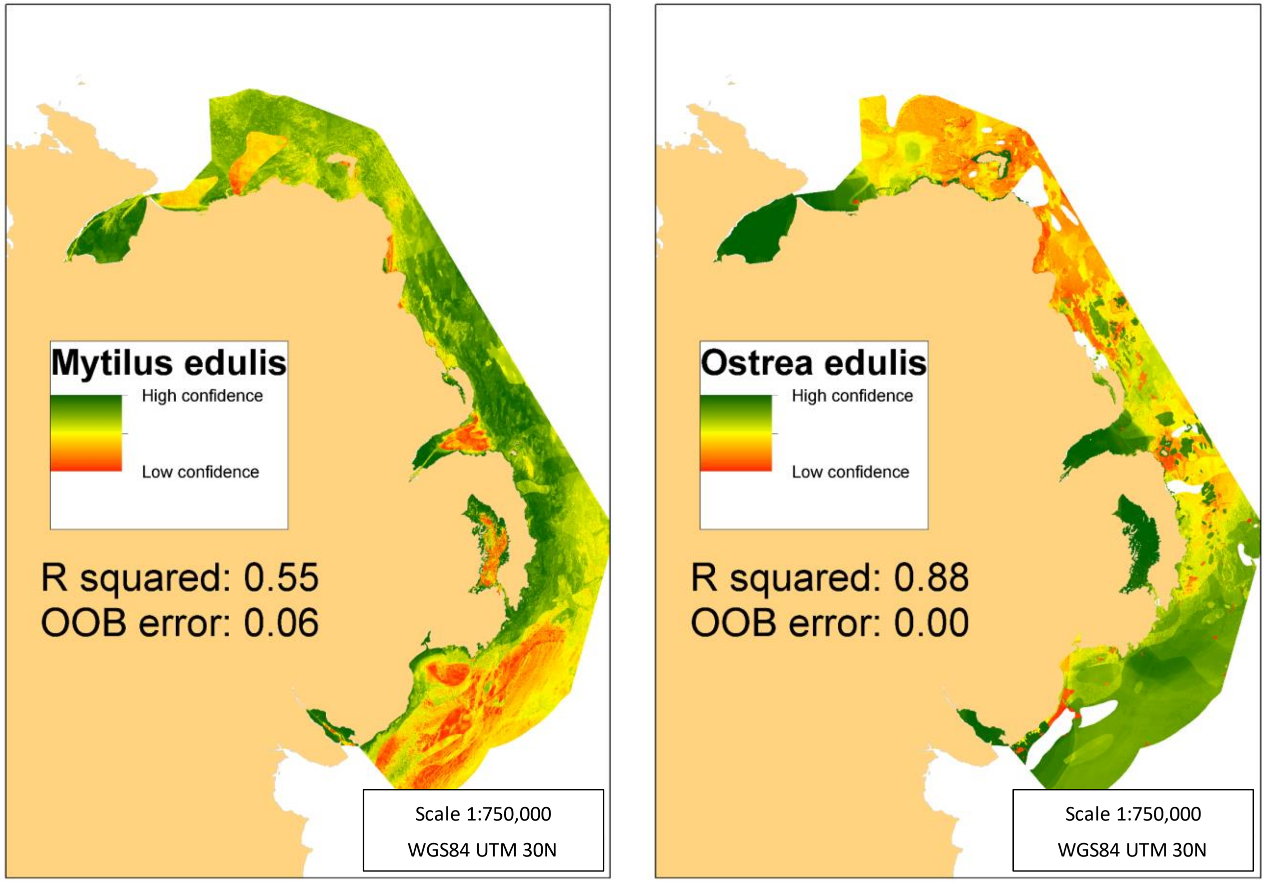


Figure 22. Model performance statistics and spatial confidence layer for Mytilus edulis (left) and Ostrea edulis (right).

Blue carbon hotspots

Figures 23, 24 and 25 show the scaled NPP, scaled CSR and BC potential (scales NPP multiplied by the scaled CSR). It must be stressed that these outputs are experimental outputs used to emphasise the importance of linkages between species and habitats that fix carbon and those that concentrate and then store carbon. As such, they should be used with care. Equally, the NPP and CSR attribution is based on generic literature values and the actual values locally are likely to differ significantly.

The scaled NPP and CSR suggest that the sea loughs are potential hotspots for BC (should all suitable habitat be occupied). It is recommended that a similar approach is used with specific species pairings to understand the best strategic approach to use to maximise BC capture and storage.

Value ranges for medium and high habitat suitability

The full set of environmental conditions associated with medium and high suitability are provided in the Appendix (Tables A2 – A17). A selection of influential environmental variables has been summarised in Tables 8, 9, 10 and 11.

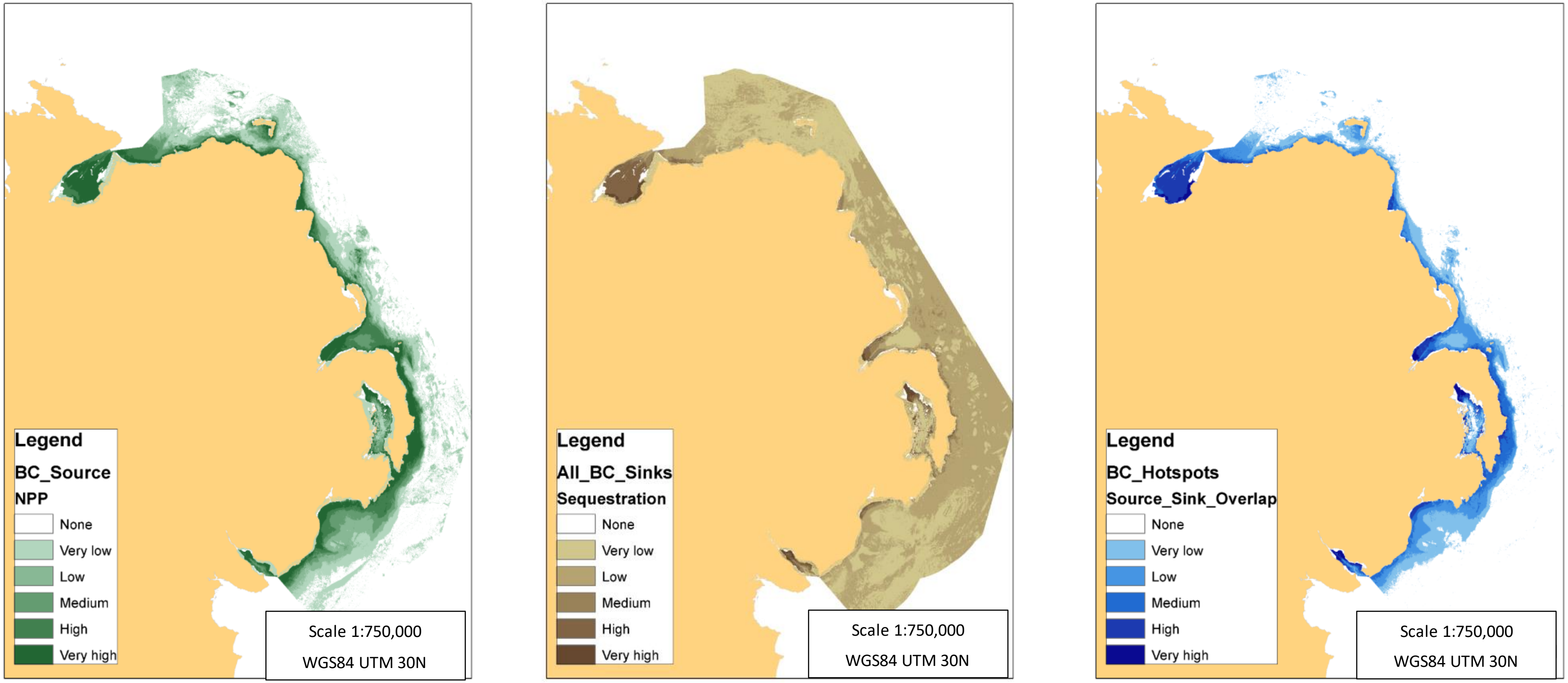


Figure 23 (left), 24 (middle) and 25 (right). Left - Net Primary Productivity (NPP) (gC/m2/yr) scaled by habitat suitability, middle - Carbon Sequestration Rate (CSR) (gC/m2/yr) and right – potential BC hotspots based on the interaction between NPP and CSR.

Table 8. A selection of environmental value ranges associated with high habitat suitability for Laminaria digitata, Laminaria hyperborea and Saccharina latissima.

	Laminaria digitata				***Laminaria hyperborea***				***Saccharina latissima***			
Variable	**Minimum**	**Maximum**	**Mean**	**SD**	**Minimum**	**Maximum**	**Mean**	**SD**	**Minimum**	**Maximum**	**Mean**	**SD**
Bathymetry	-11.1	-0.5	-5.8	2.7	-18.1	-1.8	-9.9	5.0	-13.8	-0.9	-7.4	3.2
Current	22.0	1028.0	525.1	206.6	40.3	1185.2	613.8	201.7	20.3	1143.8	581.8	210.0
Mean temperature	10.5	11.0	10.7	0.2	10.5	11.0	10.8	0.2	10.5	11.1	10.8	0.2
Nitrates concentration	0.0	0.4	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.5	0.2	0.1
PAR at seabed	1.1	23.9	12.5	3.0	0.5	20.7	10.5	3.4	0.8	23.6	12.2	2.6
Salinity	31.4	34.1	32.7	0.9	33.1	34.3	33.7	0.4	30.1	34.1	32.1	0.9
Wave kinetic energy	47.1	3820.2	1935.6	1322.6	15.2	826.8	421.1	353.7	37.9	3664.6	1852.4	1622.3

Table 9. A selection of environmental value ranges associated with high habitat suitability for *Mytilus edulis* and *Ostrea edulis*.

	Mytilus edulis				***Ostrea edulis***			
Variable	**Minimum**	**Maximum**	**Mean**	**SD**	**Minimum**	**Maximum**	**Mean**	**SD**
Bathymetry	-30.1	2.4	-13.9	26.4	-51.3	5.8	-22.8	0.0
Current	6.3	830.9	418.6	119.8	0.3	1268.6	634.5	79.8
Mean temperature	9.5	10.9	10.2	0.3	10.0	11.0	10.5	0.0
Temperature in summer	12.5	16.0	14.2	0.6	28.2	33.8	31.0	0.0
Wave kinetic energy	6.5	6486.6	3247.5	968.3	0.0	7102.0	3551.0	0.0

Table 10. A selection of environmental value ranges associated with high habitat suitability for *Zostera marina and Zostera noltei.*

	Zostera marina				***Zostera noltei***			
Variable	**Minimum**	**Maximum**	**Mean**	**SD**	**Minimum**	**Maximum**	**Mean**	**SD**
Bathymetry	-37.1	0.0	-18.6	17.0	-24.6	0.1	-12.3	15.6
Current	4.0	1257.7	630.8	167.2	0.3	1321.3	660.8	107.1
Mean temperature	10.5	11.0	10.7	0.1	10.4	11.1	10.7	0.0
Nitrates concentration	0.0	0.4	0.2	0.0	0.4	0.4	0.4	0.0
PAR at seabed	2.4	25.6	14.0	2.5	0.3	24.4	12.3	0.9
Salinity	29.6	34.3	31.9	0.2	29.6	34.0	31.8	0.2
Wave kinetic energy	20.6	2116.8	1068.5	388.1	0.6	2374.3	1187.4	176.6

Table 11. A selection of environmental value ranges associated with high habitat suitability for saltmarsh

	Saltmarsh			
Variable	**Minimum**	**Maximum**	**Mean**	**SD**
Aspect	0.9	77.6	38.0	32.7
Bathymetry	0.4	2.3	1.4	0.3
Coastal Erosion	-12.2	-9.1	-10.7	1.4
Curvature total	-0.4	0.0	-0.2	0.3
Slope	0.4	1.1	0.7	0.3

Estimation of Extent and Habitat Suitability within Northern Ireland's Inshore MPA Network

To calculate extent and high suitability area within Northern Ireland's inshore MPA network, the extent and HS polygons were clipped to the MPA network boundaries. The clip removes areas that fall outside of the MPA network boundary. The estimated areas are provided in the table 12.

A high proportion of the extent of *L. hyperborea, L. digitata, M. edulis* and *Z. marina* occur within the MPA network. A large proportion of *O. edulis* occurs outside of the network, but it is of note that an estimated 659km^2 within the network is potentially suitable for the species. Similarly, a large estimated area of 1190.4 km^2 is potentially suitable for *M. edulis* species.

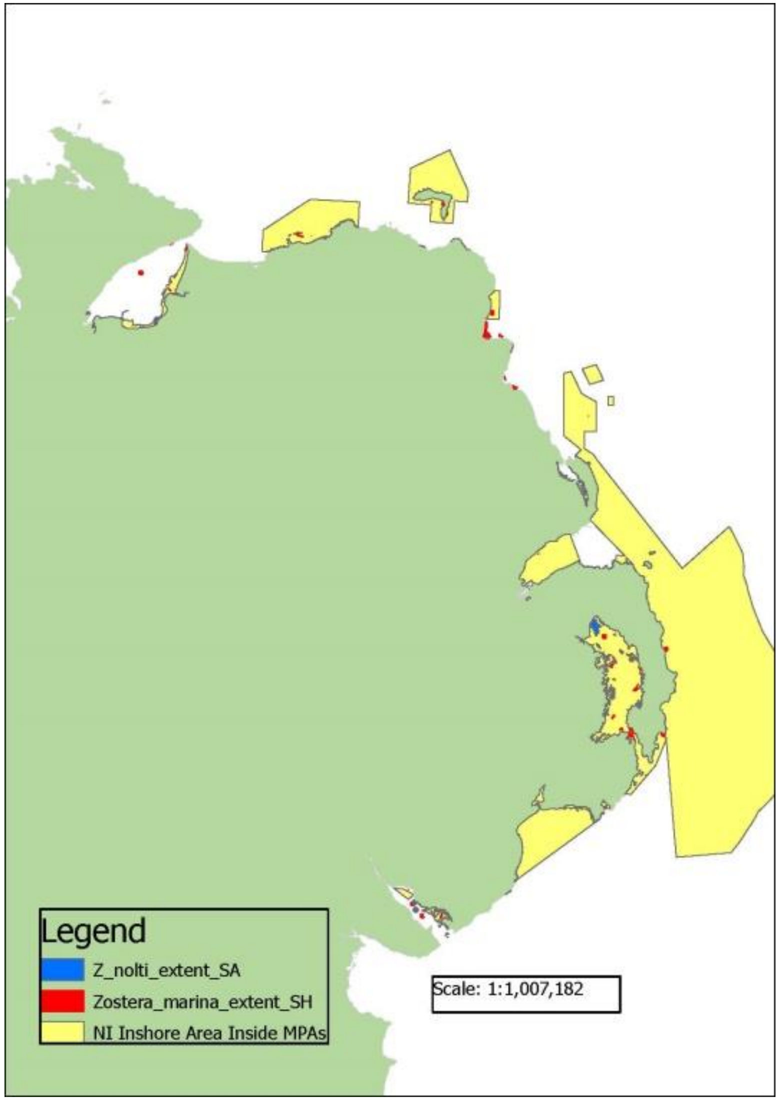
Table 12. The area of current extent, and high suitability area for all species and habitats considered, excluding *Zostera noltei,* within Northern Ireland's inshore MPA network.

Species or Habitat	Extent area in MPA network (km^2)	% of current extent within MPA	High suitability area within MPA network (km^2)
Laminaria hyperborea	55.1	67%	70.8
Laminaria digitata	65.1	78%	105.1
Ostrea edulis	41.0	24%	211.7
Mytilus edulis	97.6	69%	404.2
Saccharina latissima	92.8	68%	168.8
Saltmarsh	8.5	27%	3.2
Zostera marina	11.1	70%	38.8
Zostera noltei			23.3

Table 13. The blue carbon value (i.e. sequestration rate multiplied by the area) of *O. edulis*, *M. edulis, Z. marina* and saltmarsh in the Northern Ireland inshore region.

Species or Habitat	Sequestration rate of BC in NI inshore region (t C yr^{-1})	Sequestration rate of BC in MPA network (t C yr^{-1})	*Potential sequestration rate of BC in inshore region (t C yr^{-1})	* Potential sequestration rate of BC in MPA network (t C yr^{-1})
Ostrea edulis	8395	2049	24315	10587
Mytilus edulis	11356	7906	71159	32744
Saltmarsh	8273	2253	3644	863
Zostera marina	3571	2500	19730	8764
Total	31595	14707	118848	52958

* Potential value of blue carbon is based on high suitability area values.



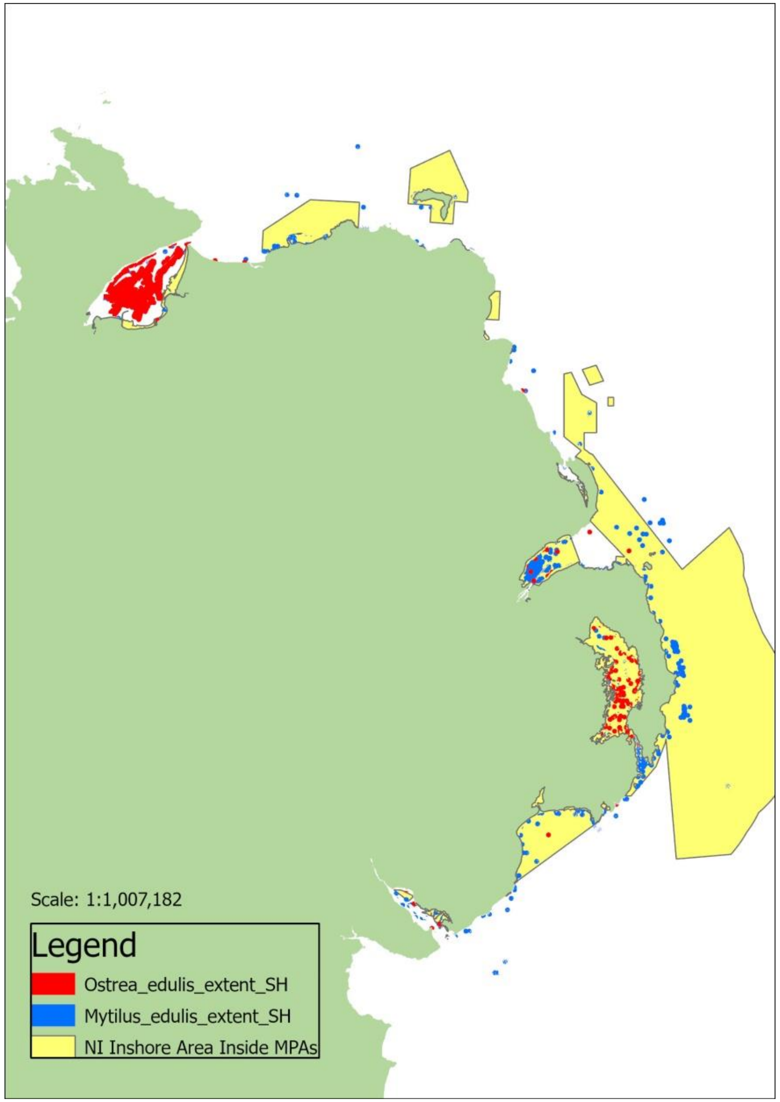
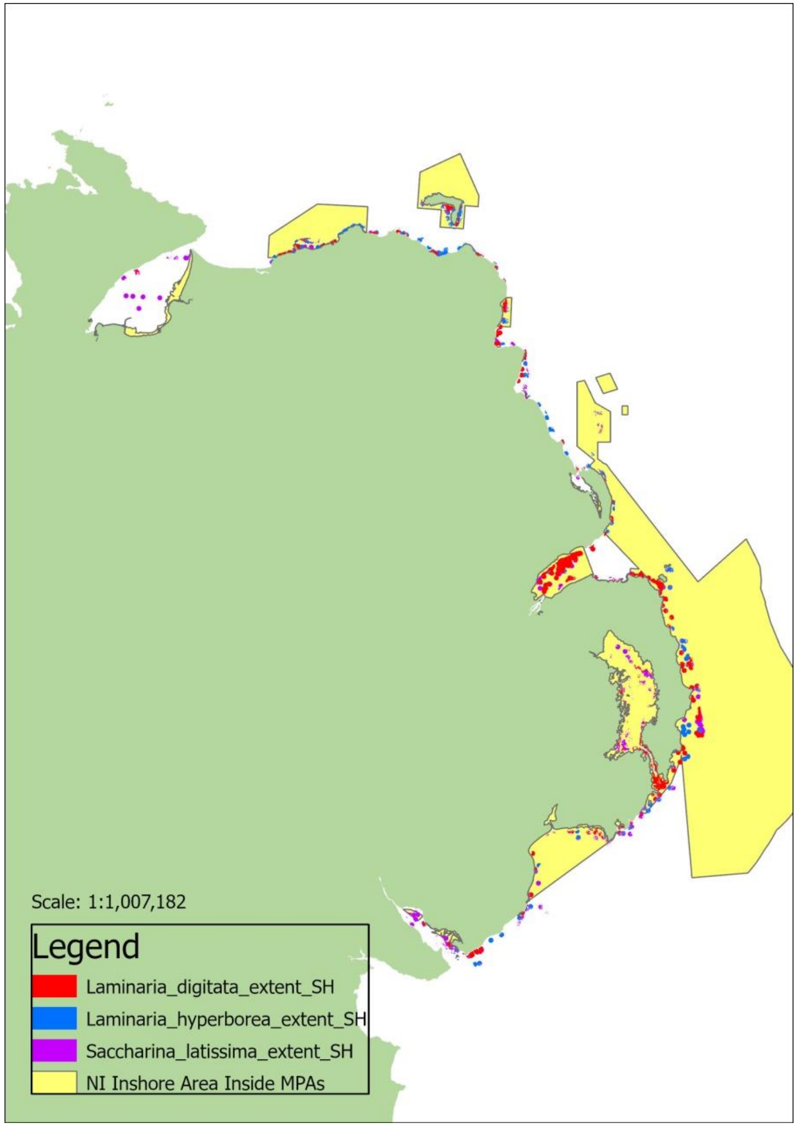
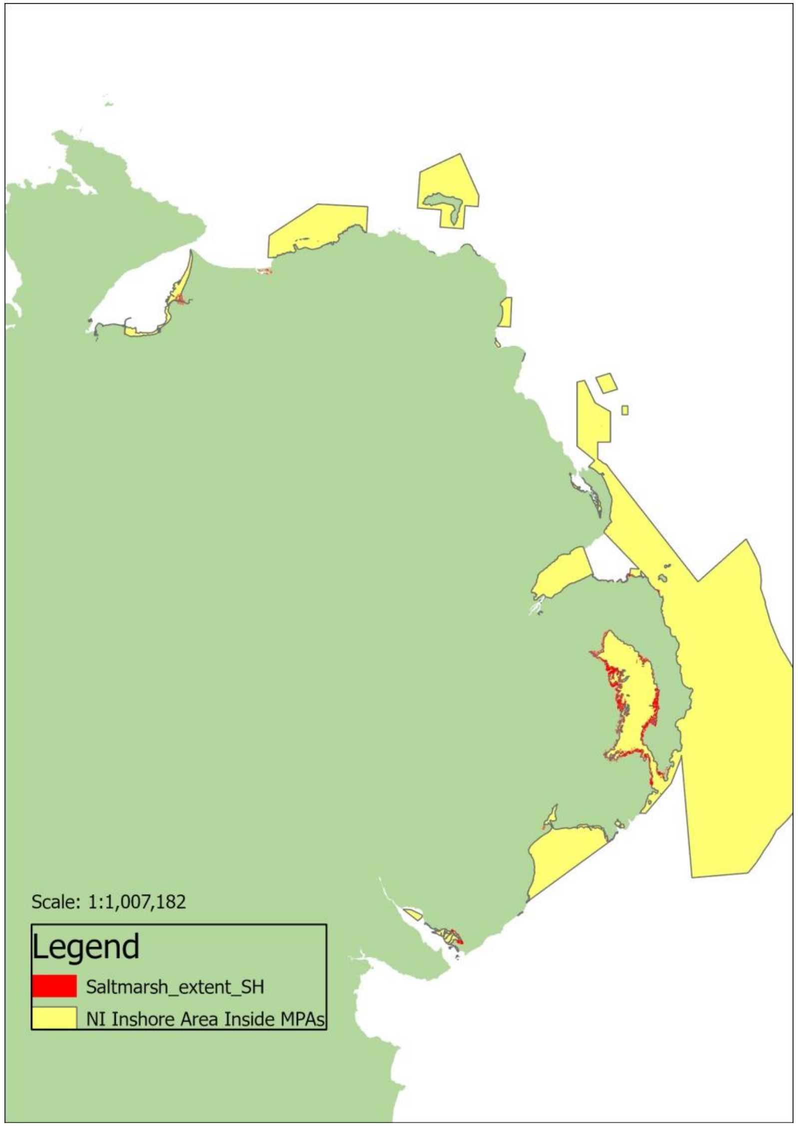


Figure 26 and 27: Estimated current extents of coastal blue carbon habitats in Northern Ireland (seagrass species on left, shellfish species on right)


Scale: 1:1,007,182
Legend
Laminaria_digitata_extent_SH
Laminaria_hyperborea_extent_SH
Saccharina_latissima_extent_SH
NI Inshore Area Inside MPAs


Scale: 1:1,007,182
Legend
Saltmarsh_extent_SH
NI Inshore Area Inside MPAs

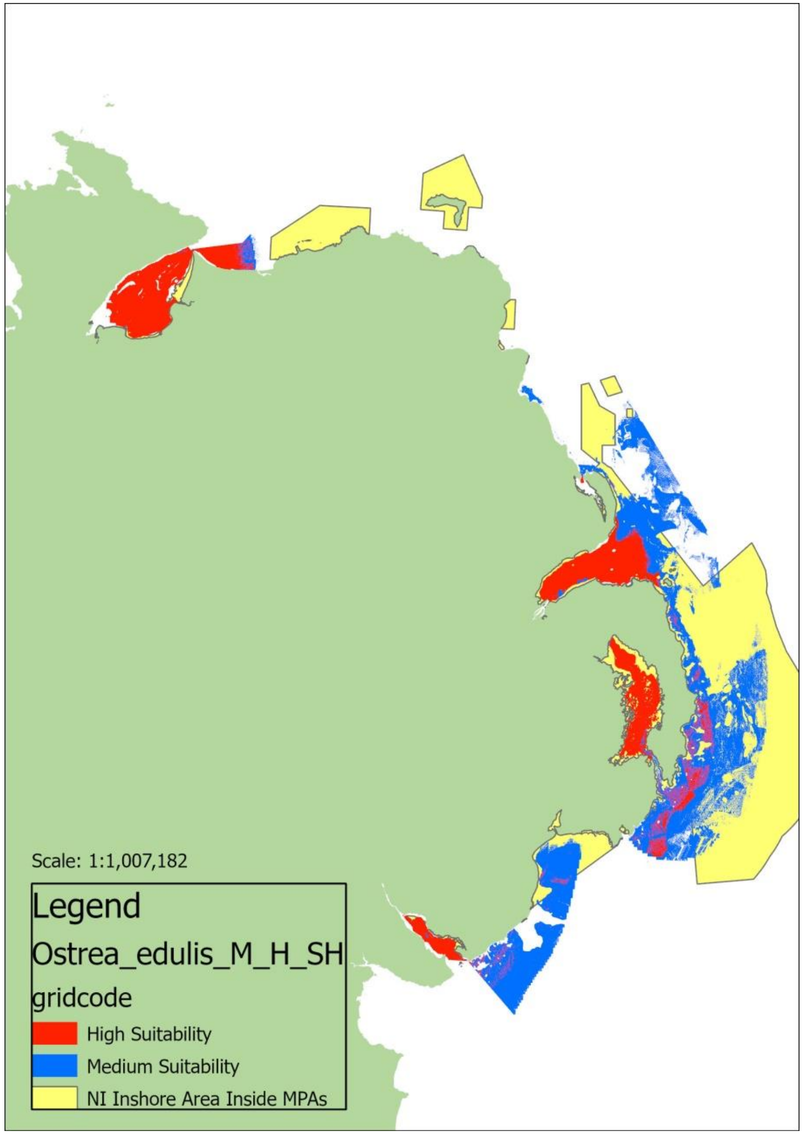


Figure 28 and 29 Estimated current extents of coastal blue carbon habitats in Northern Ireland (kelp species on left, saltmarsh on right)

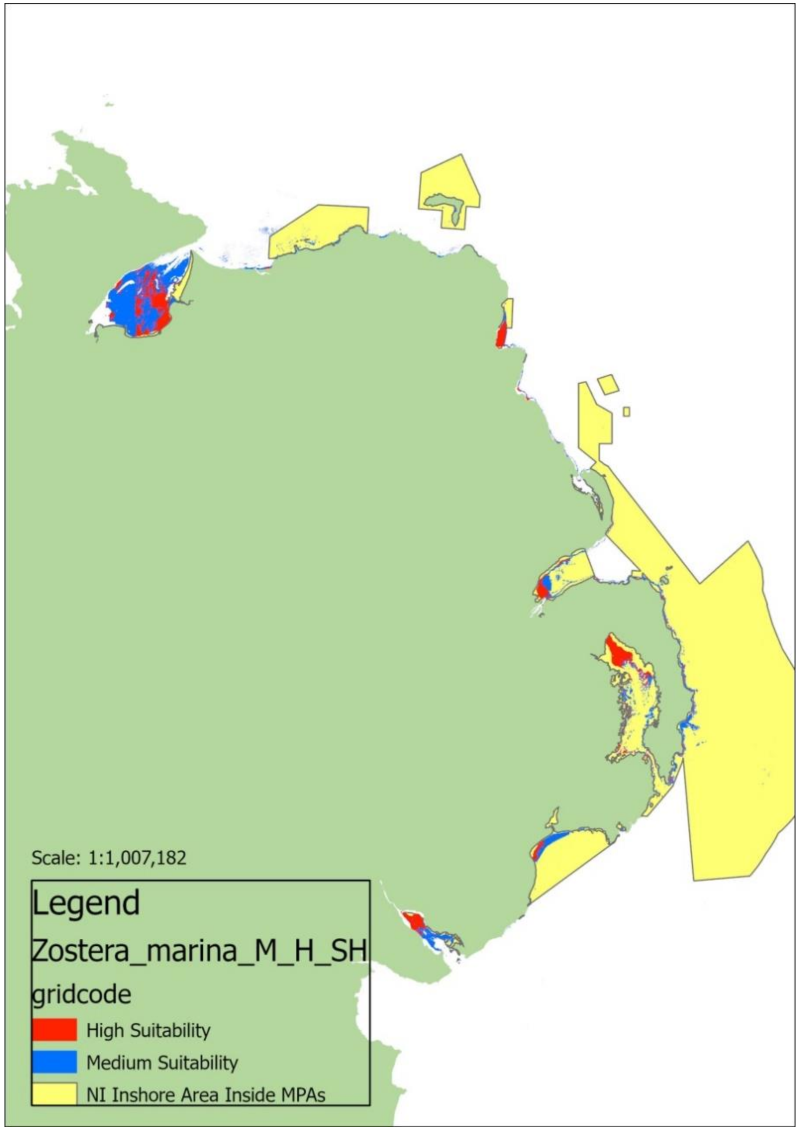


Figure 30 and 31 Estimated suitable area for *O. edulis* (left) and *Z. marina* (right).

Discussion

Estimation of Extent and Habitat Suitability

The habitat suitability modelling produced moderate to high quality maps of suitable habitat for all of the BC species considered. The models of the saltmarsh performed less well, which is probably related to the poor availability of training data (outside Strangford Lough) and the reduced availability of predictor variables for this environment. Marine spatial products rarely cover high shore environments. As such, marine predictor variables were extrapolated into the high shore but this is likely to entrain error and may poorly reflect the actual conditions present.

The estimations of extent used a relatively simple but transparent and cautious methodology. The selection of the buffer range was estimated manually. The value used was sufficient to coalesce locally clustered observations. Shorter buffer values produced areas that were too closed fitted to the presence points provided and failed to look ecologically cohesive or realistic. A single buffer value has been used for all of the species but further work may choose to tailor individual buffer values for each species or habitat. The tools used to buffer the presence points have been transferred to model builder files and the extent recalculated easily.

The area for the extent, habitat of medium suitability and habitat of high suitability has been provided for each species and habitat. The area calculation is dependent on the threshold value use to delineate low, medium and high suitability. The thresholds used were selected using expert judgement and clearly the area reported will depend on the threshold value selected. It is recommended that additional threshold values and techniques (e.g. use of percentiles rather than value thresholds) are explored to understand the sensitivity of the final maps to these settings.

The sea loughs contained a high proportion of extent (occupied habitat) and suitable habitat (unoccupied habitat) for many species – only the kelp species and the blue mussel showed a greater preference for open coastline habitats and more exposed conditions. The high proportion of extent and suitable habitat in the sea loughs also suggests spatial overlap and connectivity between carbon fixers (termed BC sources here) and BS sinks (species associated with high rates of carbon sequestration) are high. The interaction between the composite NPP (Net Primary Productivity) and CSR (Carbon Sequestration Rate) maps also highlight the sea loughs as being important BC areas.

Value ranges for the environmental variables associated with suitable habitat have also been provided within this report. Suitable conditions for many of the species have also been considered by MMO (2019a) and may be of value in supplementing the values provided here. Only a small set of environmental variables (typically five) are reported by MMO (2019a). The variable ranges reported by MMO (2019a) are for optimal, sub-optimal and not suitable ranges. The values associated with many of these suitability classes are not in found in the Northern Irish marine environment. As such, the suitable conditions based on Northern Irish environmental data and local occurrence data is likely to provide more appropriate information for site selection locally.

The composite NPP and CRS were an initial attempt to produce products that might aid in the strategic decisions of which species and locations are optimal for restoration. The attribution of each species and habitat with NPP and CSR should also provide other opportunities to derive new products from the maps provided. The species considered in this study have been provided with NPP and CSR estimates from the scientific literature. It may also be possible to locally adjust the NPP and CSR rates, and hence blue carbon value, of species and sites using some of the spatial data provided with the GIS project. For example, the proximity of habitat, such as seagrass and saltmarsh, to allochthonous inputs (riverine inputs) has been proven to be an important modifier of BC value (see Mazarrasa et al. (2018), Abbott et al. (2019) and Ricart et al. (2020)) – the location and approximate catchment size of river mouths have been included in the GIS project provided. Equally, elevation has also been seen to be an important modified of carbon sequestration rates in saltmarsh – again, this information has been provided in the GIS project. An additional map attribution that may help with site and species selection is the restorability, shown below (Table 13), and reported by MMO (2019).

Table 14. Restorability of coastal habitats taken from MMO (2019b).

NERC Habitat Name	Restorability	Evidence	Confidence	Distinctive-ness*
Coastal				
Coastal saltmarsh	High	High	High	High
Coastal sand dunes	High	Medium	Medium	High
Coastal vegetated shingle	High	Medium	Medium	High
Intertidal mudflats	High	Medium	Medium	High
Maritime cliff and slopes	Low	Low	Low	High
Saline lagoons	Medium-high	Medium	Medium	High
Marine				
Blue mussel beds	Medium	Low	Low	High
Estuarine rocky habitats	Medium	Low-medium	Low-medium	High
Fragile sponge and anthozoan communities on subtidal rocky habitats	Low	Low-medium	Low	High
Horse mussel beds	Medium	Low	Low	High
Intertidal boulder communities	Medium	Low-medium	Low-medium	High
Intertidal chalk	Medium	Low	Low	High
Maërl beds	Low	Low	Low	High
Mud habitats in deep water	Low	Low	Low	High
Peat and clay exposures	Low-medium	Low	Low	High
Sabellaria alveolata reefs	Medium	Low	Low-medium	High
Sabellaria spinulosa reefs	Low	Low	Low	High
Seagrass beds	Medium-high	Low-medium	Medium	High
Sheltered muddy gravels	Medium	Low	Low	High
Subtidal chalk	Medium	Low	Low	High
Subtidal sands and gravels	Medium	Low	Low	High
Tide-swept channels	Medium	Low	Low	High
* as defined by Defra (2012b)				

It is also recommended that the extent polygons are attributed with information describing their condition or population status. For example, heavily depleted sub-populations, such as the flat oyster in Strangford Lough, are shown as presence areas and have the same attribution as other sub-populations elsewhere that are in better condition. Many of the presence points used to create the extent polygons are also attributed with densities, cover and SACFOR coding (a semi-quantitative scale for recording abundance using 'Super-abundant', 'Abundant', 'Common', 'Frequent', 'Occasional' 'Rare' – see Strong and Johnson (2020) for an example). With further work, it would be possible to query the extent polygons and access this information. Summary statistics, presented by polygon, may be sufficient to code areas of extent by the condition. As restoration efforts are likely to be more successful in areas with existing individuals, the ability to represent extent by condition is likely to be helpful when considering what and where to prioritise.

The selection of potential sites to protect, restore or create will also be facilitated through the inclusion of human activity or pressure layers, as well as the current configuration of protected and managed areas in Northern Irish waters. Furthermore, the long-term viability of restoration and creation sites needs to be considered in relation to current climate change projections. The UK Climate Projections (UKCP) 2018[33] provides spatial surfaces for assessing the potential climate change pressures at sites in Northern Ireland.

Finally, it is recommended that Northern Ireland undertake a baseline BC inventory to provide context for future projects, i.e. for providing estimates of added value and judging future trends. A baseline inventory should consider the carbon stock in the main BC habitats and the existing or potential carbon emissions resulting from changes to those ecosystems over time. Creating a carbon inventory for a given area requires understanding: (i) the past and present distribution of coastal vegetated ecosystems linked to the human uses of the area; (ii) the current carbon stock within the project area and rate of carbon accrual; and (iii) the potential carbon emissions that will result from expected or potential changes to the landscape. Carbon emissions are normally expressed in megagrams or metric tons of carbon (C) per hectare (ha), for a given change in land use in a given time frame.

The IPCC guidelines identified “activity data” and “emission factors” as being required to calculate the carbon emissions or removals for a given area. Activity data includes geographical data showing the types of land coverage and use in a given area such as pristine mangrove forest, degraded tidal marsh, agricultural land, grassland, or aquaculture ponds; and the latter. The emission factors include changes (loss or gain of carbon) in the investigated area that has resulted from changes in land coverage and use (e.g., loss of carbon due to conversion of saltmarsh to agriculture land.

Potential Blue Carbon Value

The CSR values of *O. edulis, M. edulis, Z. marina* and saltmarsh (found in table 14) were used to estimate the potential value of blue carbon in Northern Ireland’s inshore region for these habitats and species. Total carbon sequestration rate in the inshore region was estimated as 31,595 t yr^{-1}.

MPA designations in Northern Ireland’s inshore waters include five Marine Conservation Zone (MCZ), seven Ramsar sites, nine Special Protection Areas (SPAs), 20 Areas of Special Scientific Interest (ASSIs) and seven Special Areas of Conservation (SACs). MCZs are designated to protect a range of nationally important rare or threatened habitats and species. Ramsar sites protect internationally important wetland habitats. Areas of Special Scientific Interest (ASSIs) are areas protect the best of our wildlife and geological sites. SPAs protect important bird areas and SACs protect important areas for habitats and non-bird species. Further information about MPAs in Northern Ireland is available on the DAERA website[34]. Blue carbon habitats and species present within the MPAs are not necessarily protected features of the site.

The analysis demonstrates that approximately 371 km^2 of coastal blue carbon habitats are located within the Northern Irish inshore MPA network, and is potentially storing 14,707 t C yr^{-1}. However,

[33] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/download-data
[34] https://www.daera-ni.gov.uk/articles/marine-protected-areas

only 4.48% of the inshore MPA network is favourably managed[35], and potentially damaging activities such as anchoring of recreational boats and bottom-towed fishing gear activity still occur within these sites and are possibly impacting their carbon storage capacity. Through habitat restoration within the MPA network, and implementation of management plans, there is potential to at least triple the blue carbon value of the MPA network to 52,958 (t C yr^{-1}).

This table is not an exhaustive list and additional blue carbon stores are likely to be found within and outside of the MPA network.

Conclusion

Habitat suitability modelling provides critical information that supports site selection for habitat protection, restoration and creation. Furthermore, maps of current extent also provide information on the potential availability of donor sites and, if areas of extent are in poor condition, additional candidate sites in need of protection and restoration. It has been seen in numerous studies that restoration activities often live and die by site selection. However, it would be incorrect to believe that habitat suitability modelling represents a complete site selection process. As stated in the introduction, habitat suitability modelling is unable to capture all of the environmental and ecological factors determining whether a site will be colonised or not. For example, the suitability modelling done here was, as is often the case, unable to account for predation pressure. This factor is probably the main reason why large areas of suitable subtidal habitat are not occupied by *M. edulis*. It is therefore necessary that additional site suitability checks are performed before commissioning a restoration or creation protect at a specific site. This is likely to include the confirmation of appropriate environmental conditions as well as an evaluation of predatory and competitive processes. An appropriate level of diligence is likely to also include the use of a pilot study at any potential restoration or habitat creation sites.

[35] https://www.daera-ni.gov.uk/sites/default/files/publications/daera/ni-environmental-statistics-report-2020_0.pdf

Part III: Blue Carbon Restoration Feasibility Workshop

An Introduction to the Workshop

The objectives of the workshop were two-fold. First to share knowledge about the practicalities of blue carbon habitat restoration from those with experience elsewhere in the United Kingdom and Republic of Ireland. We invited 6 guest speakers that shared their lessons learned from restoration projects focused on seagrass meadows, kelp forests, native oyster reefs, and saltmarsh. The second objective was to capture local knowledge of the areas that were identified as suitable for the blue carbon habitats in the modelling exercise.

The workshop was held on the morning of 17th February 2021. As this was a virtual workshop, the expert stakeholders recorded their discussion using Jamboard (digital whiteboard software), screenshots of which are provided in Appendix 2, along with the participant list (Appendix 3). From the discussions captured in the breakout groups a list of barriers, opportunities and pressures to blue carbon habitat restoration in Northern Ireland has been created (Tables 1 to 12).

Figure 32. Snapshot of some of the participants at the workshop

Kelp Forests

Case Study: Help Our Kelp

Help our Kelp is a partnership lead by the Sussex Wildlife Trust working to bring back kelp along the West Sussex coastline. The partnership consists of the Sussex Wildlife Trust, Marine Conservation Society, Big Wave Productions, Blue Marine Foundation, and the University of Portsmouth.

Over time, repeated passes by trawling vessels have torn kelp from the seafloor and prevented natural regeneration and so the Sussex Inshore Fisheries and Conservation Authorities (IFCA) proposed a nearshore trawling byelaw which aims to alleviate this pressure to allow the kelp to recover. The local and democratic agreement of the byelaw is the first major milestone for the preservation of kelp in Sussex, and the next critical step is for the Secretary of State for DEFRA to sign the byelaw so it can be implemented. The Help Our Kelp partnership is championing this byelaw and working to keep up the pressure on Defra to see it signed off and implemented.

Putting fisheries management in place is the first step the partnership is taking to restore the kelp forests. The next step they are taking is to bring together the key organisations which will help move the restoration project forward and support it long-term. This includes a strategic stakeholder group who will provide vital assistance in the practical elements of the work and a science group bringing expertise in kelp ecology, oceanography and social sciences. In preparation for the implementation of the byelaw, the partnership has been preparing work streams including consolidating historical and current data, identifying areas of research and data collection and lining up a programme of public and stakeholder engagement, and developing project management to bring all the work streams together.

Find out more here https://sussexwildlifetrust.org.uk/helpourkelp

Discussion Questions

Table 15. What are the barriers to kelp restoration in Northern Ireland?

Knowledge gaps	Limited historical / baseline data on health and extent of kelp
	Lack of understanding of kelp as a blue carbon habitat – where does the carbon go in NI?
	Lack of knowledge of ecosystem provision of kelp
	No best practice methodology for mapping kelp habitat
	Lack of data on pressures on kelp in NI
Required finances & resources	Cost of aquaculture
	Preparatory work costly (includes stakeholder identification, ground-truthing models)
Stakeholder engagement	Ocean literacy challenge – not a well-known species, or considered 'seaweed' and a blight because of Ulva
	Removed for health and safety issues – restoration would require education
	'Out of sight, out of mind mentality'
Pressures	Changes in range and distribution due to climate change
	Invasive species e.g. Japanese kelp (may be better blue carbon habitats)
	Removed for health and safety issues on shores and boating
Policy & legislation	Lack of marine spatial planning
	Not a priority species for protection
	No legislative remit for restoration or conservation – not a NI Priority species
	Introduction of byelaws to remove pressures
	Balance between gaining evidence while also putting protection in place to prevent further habitat degradation

Table 16. What are the opportunities for kelp restoration in Northern Ireland?

Research opportunities	Field surveying and monitoring of current extent and condition
	Assessment of why kelp is not present in high suitability areas according to model
	Use historical knowledge to map historical range and assess if priority species for restoration
	Explore timeframe of kelp restoration
	Investigate ecosystem provision of kelp
	Mechanism of restoration
	Resilience to climate change
Stakeholder & community engagement	Kelp 'forests' captures imagination and attention of public
	Collect local knowledge e.g. Seagrass Spotter app
	Collaborate with aquaculture industry and academia (seaweed harvesting expertise at QUB)
	Education on value as blue carbon habitat and other ecosystem services
	Diving groups can provide insight of distribution e.g. Sea Search NI
	Identification of vessel and fishers that would be affected by any legislation removing pressures e.g. trawling
	Tourism draw
	Work with local government
Policy & legislation	Introduction of byelaw to prevent trawling in kelp habitats e.g. Sussex Help Our Kelp
Operational considerations	Commercial interest in extraction likely to increase
	Co-restoration with scallops, oysters, salmon, aquaculture, Modiolus
	Explore circular economy uses for harvested kelp

Table 17. What pressures need to be considered to achieve kelp restoration in Northern Ireland?

Implementation of marine spatial plan	Potential conflict with marine renewable infrastructure and coastal development
Inshore dredging / trawling	Can tear the kelp and prevent regeneration
Invasive species	
Harvesting	Coppicing kelp, seeding ropes
Removal for health and safety	Navigation, shipping, fouling

Summary

Studies and surveys of kelp forests in Northern Ireland are historically rare, and much of the data are single sightings, indicating that either people do not record multiple sightings of the same kelp or forest. Workshop participants were not familiar with the extent and condition of kelp around the NI coast and thought that historical and baseline data were limited. There isn't a best practice methodology for mapping kelp habitat. Schoenrock et al., 2020 reviewed subtidal kelp forests in Ireland (including Northern Ireland) and suggested that recording effort should move toward documenting kelp ecosystems (presence of a forest) as well as abundance of indicator species within a standardized methodology. Development of a remote sensing mapping tool (via satellite or otherwise) would aid in monitoring the distribution of kelp forest distributions. It was noted at the workshop the importance of dive groups for surveying kelp.

Workshop participants highlighted many barriers concerning outreach and education including that as kelp is a subtidal species it is 'out of sight, out of mind', that it may be considered a blight similar to Ulva, and that it is actively removed in places because of health and safety issues, therefor education would be key to changing the public discourse around this habitat. However, it was clear that the Help our Kelp project has captured the imagination of the Sussex citizens using engaging imagery that represent the forest-like characteristics of kelp habitat.

Work participants discussed the array of opportunities for partnership to explore restoration potential for kelp. These include collaborating with local aquaculture industry e.g. Islander Rathlin Kelp[36] who farm kelp on ropes around Rathlin Island, academia (the seaweed harvesting expertise within Queen's University Belfast was noted), and diving group such as SeasearchNI who can provide insight in to the distribution of kelp habitat. It was suggested that commercial interest in farming kelp was likely to increase and so co-restoration options of farming kelp along with restoration of scallops, oysters and mussels should be explored, as well as considering the circular economy of kelp farming.

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[36] https://islanderkelp.com/process/

Kelp has potential to fix carbon (the process by which inorganic carbon is converted to organic compounds by living organisms), but unlike other vegetated coastal ecosystems like seagrass, do not have the ability to store carbon. This is because kelp grows on hard substrates like rock and so cannot bury or accumulate carbon in soils or sediments. Nevertheless, kelp habitat has a large aboveground biomass with high detritus export rates and therefore represent substantial carbon stocks that could sequester carbon through processes other than local burial, such as burial of allochthonous detritus in deep sea sediments in coastal areas (>400 m). However, Northern Ireland does not have deep coastal areas, so it is not understood where carbon stored in kelp ends up and these questions were raised by workshop participants.

Kelp is not a priority species or habitat in Northern Ireland and no NI MPAs have been designated to protect the habitat. It would be prudent to use historical knowledge to map historical range of kelp habitat to assess if it should be a priority habitat for restoration in NI.

Across the UK the most common approach to managing kelp forests is through preservation i.e. to avoid, prevent or limit habitat degradation and loss primarily caused by anthropogenic activities. For example, 'Help Our Kelp'[37] plans to restore Sussex kelp forests through the introduction of a new by-law to prevent trawling within 4km of the coastline, which will allow natural regeneration. The 'Help The Kelp[38]' project successfully campaigned for the prohibition of dredging of kelp in the context of increasing demands for wild kelp from pharmaceutical, food processing and textile industries.

[37] https://sussexwildlifetrust.org.uk/helpourkelp
[38] https://www.sift-uk.org/projects/help-the-kelp/

Saltmarsh

Case Study: Experimental saltmarsh restoration in Essex

Essex Wildlife Trust partnered with the Environment Agency to restore valuable saltmarsh and coastal defences in the Blackwater Estuary. The pilot project involves installing coir structures within selected creeks to encourage sediment accumulation and plant growth, protecting the saltmarsh habitat. They have used their network of dedicated volunteers to brave the cold weather and install 14 coir structures over the winter period. Each structure consists of 3 to 6 rolls, made from a sustainable coconut waste product, held together with hessian rope that is secured in the saltmarsh with chestnut stakes.

This is an experimental and low-cost approach to try and combat the degradation of Essex saltmarshes and the volunteers have been key in implementing the project.

The progress of the project will be monitored to see if this low-cost sea defence technique is successful and if it has the potential to be used at other saltmarsh sites as an effective restoration technique.

Essex Wildlife Trust will be producing a toolkit that will be available publically for practitioners implementing this technique.

Find out more here https://www.essexwt.org.uk/news/restoring-saltmarshes-blackwater-estuary

Discussion Questions

Table 18. What are the barriers to salt marsh restoration in Northern Ireland?

Ecological considerations	Should Spartina be considered an invasive species or a naturalized non-native?
	Should Spartina be used for fringing marsh projects?
	Land-sea interaction is difficult to manage
	Only small pockets suitable for restoration – does NI have areas suitable for restoration?
	Mapping can disturb birds e.g. skylarks that nest in saltmarshes
	Is their need for a buffer zone for protect salt marsh from run off?
Knowledge gaps	Mapping salt marsh is difficult e.g. predictors related to water characteristics are usually not recorded above sea level. This is causing troubles when modelling saltmarshes and extrapolation of data included in the maps.
	Identify local pressures e.g. eutrophication, grazing, and measure sensitivity to such pressures
	Impact of climate change e.g. sea level rise
Required finances & resources	Managed realignment is costly due to land prices, coastal access etc.
	Lack of funding available
	Specialized technology to survey / map required e.g. hover craft
Stakeholder engagement	Land owners and local councils using land in a conflicting way e.g. cattle grazing
	DAERA approaching can cause trust issues with landowners
	Economic benefits of salt marsh restoration are different to economic benefits of direct income from farming
	Salt marsh restoration seen as loss of land
Operational considerations	Access can be an issue in terms of health and safety and land owner permission

Table 19. What are the opportunities for salt marsh restoration in Northern Ireland?

Research opportunities	Locally adjusted figures for blue carbon storage and sequestration are needed
	Sea defence renewal costs to be incorporated in to decision making on where and when managed realignment to salt marsh should be selected
	Mapping and modelling salt marsh – survey data required
	Monitoring to establish baseline of species diversity
	Impacts of climate change must be understood before undertaking restoration activities e.g. include sea level rise in modelling
	Overlay land ownership on model
	Assess condition of current extent – is restoration required or do pressures need removing?
Stakeholder & community engagement	Opportunity to build trust with landowners
	Incorporate restoration in to management plans
	Communication to explain ecological and economic benefits of using land in this way necessary
	Quick and visible results support public engagement
	Education for those making decisions about coastal management as confusion when water coming back in
	Opportunity to work with local councils and other interest groups e.g. birders
Policy, legislation & funding	More interest may lead to better policy and more funding
	Agri-environment schemes for grazing to levy funding
	Consider circular economy e.g. identify sources of sediment to input into the saltmarsh e.g. dredging
	Development of shoreline management plans
Operational considerations	Should Spartina be considered an invasive species or a naturalized non-native?
	Should Spartina be used for fringing marsh projects?
	Opportunity for managed retreat
	Should easy small sites be chosen first or more challenging sites that may have more pay off?
Partnership working	eNGOs are landowners e.g. Wildfowl and Wetland Trust, National Trust, RSPB

Table 20. What pressures need to be considered to achieve salt marsh restoration in Northern Ireland?

Invasive species	e.g. Spartina
Local farming	Sheep waste issues if sheep grazing / controversy between usage for sheep vs shellfish (water quality) / sensitivity to agri runoff
Climate change	Sea level rise can affect saltmarsh growth and cause coastal squeeze along with coastal development
Storm events	Can cause coastal flooding, and deliver large volumes of sediment to the saltmarsh, and cause marsh edge erosion
Coastal developments	Coastal defences and dredging have the potential to increase the vulnerability of saltmarshes to climate change, and by diminishing sediment supply, human developments can slow down marsh growth and reduce marsh recovery capacity.

Summary

The estimated total extent of saltmarsh in Northern Ireland is approximately 3130 ha, this equates to around 7% of the total UK saltmarsh area (45,500 ha) (NI Habitat Action Plan – Coastal Saltmarsh, DEARA, 2005); however, the coast of Northern Ireland forms 2.7% of the total UK coastline and so there is potential for Northern Ireland to contribute significantly to saltmarsh habitat in the UK. Around 100 ha of saltmarsh are lost in the UK annually due to a variety of factors, but the extent of loss of saltmarsh in Northern Ireland alone is unknown (NI Habitat Action Plan – Coastal Saltmarsh, DEARA, 2005). The most extensive estuarine salt marshes are found in the Roe Estuary in Lough Foyle, around Strangford Lough, at Ballycarry in Larne Lough, in the Bann Estuary and at Mill Bay in Carlingford Lough (NI Habitat Action Plan – Coastal Saltmarsh, DEARA, 2005).

125 miles of NI Coastline are owned and protected by the National Trust, including saltmarsh at Strangford, the Barmouth, Ballymacormick Point and Dundrum coastal path, in fact, the National Trust have 85 ha of saltmarsh within its property; one fifth of all saltmarsh habitat in NI. Other NGOs, such as the Wildfowl and Wetlands Trust (WWT) and the RSPB, also own or manage several other important saltmarsh sites in Northern Ireland. These owned areas often benefit from a warden/ranger service that encourages appropriate management and control of damaging activities and provides educational services. They all contribute to coastal zone management initiatives in Northern Ireland.

When saltmarsh habitat in NI sits within a MPA it may be protected from potentially damaging operations and through the application of targeted conservation objectives. For example, saltmarsh habitat within NI is currently afforded protection under Bann Estuary SAC, Murlough SAC, North Antrim Coast SAC and Strangford Lough SAC (notified features are Annex I 'Atlantic salt meadows'). The targets within the current habitat action plan for coastal saltmarsh are:

- Maintaining the current extent of all saltmarsh at 250ha.
- Maintaining the area of saltmarsh in favourable condition at 135ha
- By 2015, restore to favourable condition the area of saltmarsh in unfavourable condition (100 ha)

The conservation status (i.e. favourable or unfavourable condition) is determined by the habitat's condition as defined by targets or target ranges for a series of different attributes, which include components or characteristics of the vegetation. The carbon storage and sequestration potential of saltmarsh are not stated within the habitat action plan or associated protected area designation documentation.

For salt marsh there is a strong body of evidence to suggest that restoration measures should be possible (MMO, 2019). But, there is limited saltmarsh management options and restoration activities in NI, and it is not included in shoreline management plans. However, management through farming incentives (e.g. Countryside Management Scheme) are common, with saltmarsh is defined as ‘coastal farmland’, but schemes relate more to ASSI designation than specific saltmarsh sites. The Strangford Lough Wildlife Scheme, created by the National Trust, also manages and controls disturbance of the intertidal mudflats at Strangford Lough.

Restoration of saltmarsh through managed realignment seems the most valuable coastal blue carbon initiative in terms of quick impact. Still, it comes at a high cost due to land prices, coastal access etc. To overcome this, restoration practitioners must have good community negotiations. Furthermore, the infrastructure is visible and of public interest, and reclamation of land for restoration can be seen as loss of agricultural land, reaffirming that community engagement and education is vital. There is an opportunity to demonstrate the ecological and economic benefits of using land in this way which should include sea defence renewal costs and be incorporated into any decision making on where and when managed realignment of salt marsh should be selected.

Baseline data on species diversity is required as a comparable measure of success of restoration, as well as to assess the condition of the current extent. The DAERA Intertidal Ecology Team currently surveys saltmarsh, and mapping took place in 2020 in the northern area of Strangford Lough. Using an Unmanned Aerial Vehicle (UAV) to overcome access and safety issues, they will map the seagrass alongside the saltmarsh in this area. Expert stakeholders at the workshop stated there were opportunities for saltmarsh restoration in Strangford Lough and Lough Foyle, especially from Longfield to Magilligan Point (where there are no restrictions regarding cross-border issues as saltmarsh is a coastal habitat), and possibly Belfast Lough. However, questions were raised about whether the small pockets of saltmarsh around the NI coast would be suitably large enough for restoration and if buffer zones to manage retreat or protect areas from run-off are needed. The National Trust is undertaking a Spartina survey around Strangford Lough this year which will help to assess condition of saltmarsh.

Whether Spartina should be considered an invasive species or a naturalised non-native was discussed, along with the opportunity to use the species for fringing marsh restoration projects.

A DAERA staff member noted at the workshop that the saltmarsh maps are missing areas where saltmarsh currently occurs, e.g. Dundrum Bay. Mapping salt marsh is difficult because predictors related to water characteristics are usually not recorded above sea level. This has caused troubles when modelling saltmarshes and extrapolation of data has been used in the maps.

Seagrass Meadows

Case Study: Seagrass Ocean Rescue

Project Seagrass together with Sky Ocean Rescue, WWF, Cardiff University, Swansea University and Pembrokeshire Coastal Forum launched 'Seagrass Ocean Rescue'. This is the largest seagrass restoration project in the United Kingdom and it aims to restore 20,000 m^2 (approximately 2 rugby pitches) of seagrass habitat. This involves the collection of 1 million seeds to plant in the Dales Bay in Wales. The hope is that the pilot project will create a model that could lead the way for large-scale seagrass restoration throughout the UK.

They will be collecting over 1 million seeding shoots of *Zostera marina*. Once these shoots have been collected they are taken to the aquaria facilities at Swansea where they are processed to separate the seeds from the leaf tissue.

Planting the seagrass entails laying lines of small hessian bags onto the seabed. All the materials are natural fibres that will rapidly degrade over a 6 to 12-month period. The lines are laid using a small boat and then divers will tend to the lines once laid to ensure they are well placed. Each of the hessian bags will contain a small amount of sand and some seeds. The planting phase lasts 2 years, and then the monitoring phase begins over a 5-year period.

Natural Resources Wales will be the regulator for the project, granting the partners a license to plant seagrass. The project team is working with the community, including mooring holders, fishers and other interest groups to find suitable areas to plant the seagrass. No formal restrictions will be made on users such as mooring holders, commercial users or fishers. Swansea University is hoping to work with the fishers in the area to have a voluntary agreement to mark out and avoid the planting area during the initial sowing and growing period. Beyond that period fishing practices, such as gill net fishing and prawn pots, have been discussed with local fishers as a sustainable option for catching fish in the meadow.

Find out more here https://www.projectseagrass.org/seagrass-ocean-rescue/

Discussion Questions

Table 21. What are the barriers to kelp restoration in Northern Ireland?

Knowledge gaps	Lack of knowledge of genetics and associated considerations for restoration
	Lack of historical baseline data
	No 'right' methodology for ensured successful restoration
	Point data (i.e. where it is) available, but lack of data on size and shape of patches
Required finances & resources	Infrastructure required can be costly
	Preparatory work can be costly and take time e.g. obtaining licenses, identifying landowners
	Impact of Covid-19
	Special expertise required e.g. divers which can be costly
	Seed availability
Stakeholder engagement	Potential sites for restoration used by multiple groups e.g. recreational boating, commercial fishing
	Getting community buy-in to remove pressures can be difficult
	Potential negative response from local government
Cross-border working	No agreed border in Lough Foyle
Ability to manage pressures	Management of current impacts such as dredging
	Sediment quality may make restoration unviable
	Stochastic events cannot be controlled e.g. storms
	Disease
Policy & legislation	Challenging mechanisms to initiate restoration e.g. SEA
	Legislation not in place e.g. current MPA network does not consider blue carbon value of sites
	Management plans don't currently set out sites for restoration

Table 22. What are the opportunities for seagrass restoration in Northern Ireland?

Research opportunities	Investigate genetics and associated considerations for restoration – existing genotypes may tolerate more difficult conditions
	Investigate connectivity of sites
	Investigate current pressures and climate projections – include as data layers on habitat suitability models
	Assess conditions of priority areas for restoration for suitability
	Determine condition of existing seagrass meadows and consider connectivity to priorities areas for restoration e.g. Strangford Lough
	Remote sensing to collect size and shape data of meadows
Stakeholder & community engagement	Education for all user groups
	Public support for restoration projects evidenced from other projects
	Community engagement is an important source of people power
Policy & legislation	Blue carbon as policy lever for restoration
	Recognize blue carbon value of already designated MPAs
	Legislation to address hierarchy of blue carbon habitats against other species
	Development of habitat specific blue carbon codes similar to United National Blue Carbon Code of Conduct[39]
	Government subsidies to shellfish industry, to grow shellfish in a more environmentally-friendly way
	Incorporate in to incoming climate change legislation e.g. Climate Change Bill for NI
Operational considerations	Expansion of existing MPAs if conditions are suitable to allow for restoration
	Co-restoration with other habitats e.g. oysters
	Establishment of seagrass nursery for restoration
Cross-border working	Working with land owners and partners locally and in the Republic of Ireland

[39] UN BC Code of Conduct https://news.gefblueforests.org/blue-carbon-code-of-conduct

Table 23. What pressures need to be considered to achieve seagrass restoration in Northern Ireland?

Eutrophication	Nutrient loading from urbanization, run off from agricultural activities and aquaculture can increase the risk from disease, increase growth in epiphytes and promote smothering by algae
Siltation	From adjacent land management, shoreline erosion, dredging, dumping, boating, fishing and aquaculture can decrease light availability impacting productivity
Physical disturbance	From anchoring & mooring which can cause scarring, uproot seagrass or expose roots
Strom events	Can increase mobilized sediment, reducing light availability, increasing smothering threat from burial and erosion, and potential to cause physical disturbance.

Summary

Management of seagrass habitat in Northern Ireland has been focused on where it occurs within MPAs. The Waterfoot Marine Conservation Zone (MCZ) designated in 2016 is a 0.811km^2 area on the east coast of Country Antrim comprising of mainly sand and gravel sediments. This area also contains a large subtidal seagrass bed (*Zostera marina*) on infralittoral sand that may be the largest in Northern Ireland, and is considered to be in good condition, although, the seagrass bed is made up of smaller seagrass meadows that appear to be reproductively viable (seed bearing), are variable in extent, and patchy with density varying annually.

This MCZ was nominated by Seasearch Northern Ireland (NI). Volunteers from Seasearch NI first surveyed this site in 2008 and then again in 2009 and 2012, recording seagrass presence on all occasions. This emphasizes the importance of working with dive groups and citizen scientists.

Condition of the seagrass was assessed as favourable in 2016, and pelagic and demersal fishing gear activity has been allowed in the site since its designation. There has also been increasing popularity of the area for leisure and recreational activities which may be a threat for the sustainability of the subtidal seagrass beds.

Seagrass is also present in other MPAs, e.g. Strangford Lough MCZ, but as it is not the feature habitat, and bottom-towed fishing gear activity occurs throughout Northern Ireland's inshore MPAs so the habitat does not receive defacto protection.

There is a growing body of evidence to suggest that restoration measures should be possible for seagrass, and these methods have been discussed in Part 1: A review of seagrass restoration potential. Community buy-in is important for seagrass restoration projects to reduce pressures as these habitat areas tend to be multiple use e.g. fishing, diving, boating etc. Community support can also be an excellent source of person power. The process of collecting seeds, preparing materials (e.g. hessian bags with seeds), planting and monitoring requires not only monetary resources, equipment and time, but also many working hands. However, experts are required and this adds to the cost of a seagrass restoration project. Surveying and monitoring of the planted seagrass is required approximately every 2 months, and this may have to be done by divers.

Shellfish Beds

Case Study: DEEP

The Dornach Environmental Enhancement Project is delivered through a partnership between Glenmorangie, Hariot-Watt University and the Marine Conservation Society. The project's first phase trawled archaeological records, ancient literature and fisheries records, then sampled shell material, to show that oysters had existed in the Dornach Firth up to 10,000 years ago – and that reintroducing them was feasible. Next they placed 300 oysters on 2 sites in the Dornach Firth in ballasted bags to confirm that they would thrive in the water, and saw a survival rate of 86%!

The second phase used waste shell from the scallop and mussel industry to cover the seabed in the 2 locations to form a series of reefs for the oysters. This mimics the conditions on which the oyster would have grown before. They will then place a total of 20,000 oysters on these reefs. They will be monitored every 6 months, and the plan is to increase the numbers to 200,000 within 3 years, and to 4 million over around 40 ha in 5 years. At this stage, they believe the reefs will cover an area and density most likely to ensure a self-sustaining osier population replicating the number which would have existed before the species was wiped out in the 1900's.

Glenmorangie is a distillery in the local area that provided seed funding for the project. They have also commissioned an anaerobic digestion (AD) plant on site to help purify the waters of the Firth. The AD will clean 95% of the waste left over from the distillation process which gets put back in to the sea. The remaining 5% gets taken care of by the oysters which are natural bio-filters. Within 10 years, established oyster reefs will comfortable soak up the remaining 5% by ingesting plankton and other matter.

Find out more here https://nativeoysternetwork.org/portfolio/deep/

Discussion Questions

Table 24. What are the barriers to shellfish restoration in Northern Ireland?

Ecological considerations	Availability of stock without disease esp. when scaling up
	Significant quantities and large extents required
	Restoration or restorative mariculture?
	Biosecurity risks
Knowledge gaps	Blue carbon gains from shellfish restoration (subtidal vs intertidal)
Required finances & resources	Availability of stock at a reasonable price
	Licenses and permissions are costly and lengthy processes
	Issues around licensing for restoration activities
Cross-border working	MPA's not successfully designated due to border issues
Policy & legislation	No legislation to prohibit intertidal harvesting
	Gaps in NI's ecologically coherent network e.g. Outer Ards Area of Search not designated for horse mussel yet

Table 25. What are the opportunities for shellfish restoration in Northern Ireland?

Research opportunities	Co-restoration with seagrass or horse mussels
	Ensure understanding of sediment dynamics/hydrodynamic regime to situate projects
	Lessons learned from restoration of native oyster in Strangford Lough
	Pacific oysters can provide the same type of ecosystem services. Could we use them to restore degraded habitat, for restoring native oysters?
	Sustainable fishery model to sell pacific oyster - changing opinions about them as a food source (barrier of peoples taste for them)
	Investigate potential genetic inbreeding
Stakeholder & community engagement	Partnership with the Loughs Agency
	Partnerships with hatchery's
Policy & legislation	Identification of policy and business drivers

	New legislation to prohibit intertidal harvesting
	Legislation in Lough Foyle can close areas for restoration and close if bed stock drops
	Legislation in place since 2008 enforcing minimum landing size
Operational considerations	Would increasing the hatchery decrease the cost?
	Local populations may help with supply for restoration
	Subtidal restoration potentially more successful as no poaching occurs

Table 26. What pressures need to be considered to achieve shellfish restoration in Northern Ireland?

Invasive species	e.g. the slipper limpet
Poaching / unregulated harvesting	The legislation around intertidal harvesting is not clear to general public
Climate change	Sea temperature rise, ocean acidification, changes in wave exposure
Physical disturbance	Towed demersal fishing gear, scallop dredging, cable laying and activities that generally cause seabed disturbance

Summary

95% of oyster habitat in the UK and the Republic of Ireland has been lost. In Northern Ireland, native oysters have historically been fished in the loughs. There has been a fishery in Lough Foyle since 1436, and today it is one of the last remaining wild fisheries in the UK and Europe. There was a commercial fishery in Larne Lough until the late 1700's, where landings replenished Scottish and English beds. This fishery became non-function in 1883. Commercial fishing for native oyster also occurred in Belfast Lough from 1780 and became non-functional by the early 1900's. Between 1830 and 1846, more than 1,500 tonnes of oysters were harvested annually from Strangford Lough, which became a non-viable fishery by 1903. And in Carlingford Lough, a commercial fishery whose landing replenished Clontarf beds began in 1760, and became non-functional by 1903.

The current status of native oysters in Northern Ireland's loughs:

- Lough Foyle - fishery managed by the Lough's Agency but under pressure.
- Larne Lough – low-density in the intertidal and subtidal beds and population dynamics are unknown.
- Belfast Lough – low-density in the intertidal and subtidal beds and population dynamics are unknown. There are also witnessed accounts of unregulated harvesting of intertidal beds
- Strangford Lough – there has been significant amounts of unregulated harvesting of intertidal beds witnessed, and subtidal status unknown.
- Carlingford Lough – low-density in the intertidal and subtidal beds and population dynamics are unknown.

(taken from Dr. D. Smyth's presentation at the workshop)

There are many *Ostrea edulis* restoration projects taking place across Europe with an estimated financial commitment to native oyster restoration estimated at > €17,000,000[40]. Significant native oyster restoration (Table 27) is also taking place across the UK and ROI with an estimated financial commitment of > £8,000,000. Currently there are no shellfish restoration projects in Northern Ireland. Although, examples of preservation activities have been successful in Strangford Lough for the horse mussel (*Modiolus modiolus*) following a ban on mobile gear within the SAC, implementation of a no-take zone, and the introduction of bylaws to prevent diving, mooring and anchoring. Active restoration was not successful in this area and required translocation of significant amounts of horse mussel from other sites.

Table 27. List of native oyster restoration projects in Europe, UK and ROI

Scotland	England	Wales	Republic of Ireland	Europe
DEEP-Dornoch Firth	ENORI-Blackwater, Crouch, Roach and Colne (MCZ)	Mumbles Oyster Res-Swansea Bay	CuanBeo-Galway Bay	Belgium -Offshore North Sea/ Parkwindfarms and OD Nature (H2020)
CROMACH-Loch Craignish, Argyll	MARINEFF-INTEREG collaboration with France	Angle Bay-Swansea Bay	Clew Bay-Co. Mayo	Croatia –University of Dubrovnik and Mali StonAquaculture
Wild Oysters-Firth of Clyde	Solent Oyster Restoration Project-South Coast	Wild Oysters-Conwy Bay	LoghSwilly-Co. Donegal	France - Ifremerand CRC Bretagne (Aquaculture Innovation)
	Wild Oysters-Tyne & Wear		NORI-Arklow Bay Co. Wicklow	Netherlands - WWF, Gemini Wind and ARK (National Lottery)
	Humber Aquaculture Partnership			Germany I - AWI and BFN, hatchery (Fed Agency Nature Con)
	Saving Ester-FalEstuary			Germany II - AWI offshore N Sea (Fed Agency for Nature Con)
				Sweden – Swedish Env. Re. Ins. AquaVitae (H2020)

All loughs in Northern Ireland are thought to still have assemblages in-situ and workshop participants discussed if the conditions for native oyster restoration are suitable, but noted that population status needs to be established, as well as particle tracking, hydrodynamics modelled and the substrate mapped. A Horizon 2020 project application to restore native oysters in Strangford Lough has been submitted by the National Oceanography Centre, University of Bangor and Queen's University Belfast.

The historical distribution and abundance of shellfish beds in Northern Ireland's waters was discussed and workshop participants thought that restoration projects could help to bring shellfish beds back to the coastal communities' collective memories. Collaboration with a wide range of groups such as schools, citizen scientists, NGO's, commercial stakeholders, government bodies and the general public have been key factors in the success of other restoration projects and should be replicated here.

The ecological benefits of shellfish bed restoration were discussed which included increased water quality, reduction in turbidity, increase in habitat complexity, biodiversity increase, increase in

[40] https://noraeurope.eu/nora

commercial species. There can also be economic benefits as noted in D. Smyth's presentation from Grabowski et al., 2012:

- Nitrogen removal value per ha £5000 per annum
- 2.6kg of commercial crustacean per $10m^2$ per annum
- £4.50 of finfish per $10m^2$ per annum

Conclusion

For some habitats, there is a strong body of evidence to suggest that restoration measures should be possible, although restoration success in Northern Ireland has to date been limited.

Some restoration and creation methods rely on the sourcing or harvesting of seed or brood stock (e.g. establishing *Zostera* spp. or *O. edulis* beds), and in many cases suitable sources may be scarce or themselves located within existing marine protected areas. However, there may be opportunities to partner with organisations that have expertise or management oversight of these existing resources.

Measures of success should be set in a historic context and baseline data is required which is not available for all blue carbon habitats. Measures of habitat extent, carbon sequestration rates, estimated total carbon storage and pressure layers are required. An inventory of all blue carbon habitats in Northern Ireland should be developed as well as a national strategy which prioritises blue carbon habitats and areas for creation, restoration and preservation.

Preservation of habitats through the removal of anthropogenic pressures such as pollution, mooring or fishing can be a highly efficient approach and must be considered alongside the creation of new blue carbon habitats in places they are currently not existing, and the restoration of current habitats. And while there are limitations to blue carbon habitat data there must be a balance between gaining evidence while also putting protection in place to prevent further habitat degradation.

DEFINITIONS

Restoration: the manipulation of the physical, chemical, or biological characteristics of a degraded site, with the goal of enhancing natural functions or species communities in an existing habitat.

Creation: the manipulation of the physical, chemical, or biological characteristics of a site to develop a habitat that did not previously exist.

Preservation: an action to remove a threat to, or prevent the decline of the condition of a habitat or species.

(MMO, 2019b)

Potential Partnerships

Table 28. Potential partners in Northern Ireland for blue carbon habitat restoration projects

Government & Government Bodies	NGO's	Research and Academic Institutes	Other
Local councils	Ulster Wildlife	Queen's University Belfast	Islander Rathlin Kelp
Department of Agriculture, Environment, and Rural Affairs (DAERA)	National Trust	Ulster University	Bord Iascaigh Mhara
The Crown Estate	Wildfowl and Wetlands Trust	University of Bangor	Royal Yacht Association
Inshore Fisheries Partnership Group	Royal Society for the Protection of Birds (RSPB)	Agri Food and Biosciences Institute (AFBI)	Belfast Harbour

Seafish	Project Seagrass	Geological Survey Ireland (GSI) - LiDAR public feature idenfication	Warrenpoint Port
Centre for Environment Data and Records (CEDaR)	Keep Northern Ireland Beautiful (KNIB)		Angling clubs
The Loughs Agency	Citizen Sea		Seasearch NI / Dive NI
Joint Nature Conservation Committee (JNCC)	Coastwatch		Boat clubs
Strangford Lough and Lecale Partnership (SLLP)			The Peninsula Kelp Company
			Sea Grown
			Maccaferri Solutions
			Anglo North Irish Fish Producers Organisation
			Northern Ireland's Fish Producers Organisation

The role of eNGO's in blue carbon habitat restoration

There are many roles for eNGOs in blue carbon habitat restoration; for example, Ulster Wildlife has taken the lead in producing this report on the feasibility of restoration options for blue carbon habitats in Northern Ireland, building a foundation of knowledge for future restoration work. Other examples of eNGO's experience and expertise in these areas are highlighted in the case studies.

NGOs can be pilots for larger government projects by their ability to act more quickly than government bureaucracy. However, the lengthy process of NGO's obtaining licenses for restoration work was noted by workshop participants. The expertise within NGO's can also be used profitably as consultants to environmental authorities.

eNGOs are made up of professionals concerned about the environment and have a readymade network of enthusiastic citizen scientists. As such, NGOs have rich human resources that can be used in the conservation of coastal and marine habitats and biodiversity. They also use interpersonal communication methods and have recognised the appropriate community entry points for initiating conversation and establishing trust of the community they seek to benefit. NGOs can facilitate communication upward from people to the government and vice versa and are in the unique position to share information horizontally, networking between other eNGOs and organisations doing similar work as proven by the shared learning during the workshop hosted by Ulster Wildlife. They can also act as teachers in public awareness programmes for the community.

NGOs such as the National Trust and the Wildfowl and Wetlands Trust own and manage large areas of the coast and play an important role in habitat in these areas. They also have the option to purchase land specifically for restoration. Additionally, NGOs can provide technical assistance and training to assist governments and other organizations undertaking similar restoration activities. For example, Ulster Wildlife has expertise in using coir rolls for peatland restoration, a technique that can be applied to coastal wetland restoration, and the Essex Wildlife Trust is producing a toolkit for this methodology.

Potential Funding Opportunities

Table 29. Potential funding opportunities

DAERA	NIEA Challenge Fund, Environment Fund
PEACE PLUS	A new funding programme designed to support peace and prosperity across Northern Ireland and the border counties of Ireland, building upon the work of the previous PEACE and INTERREG Programmes.
National Lottery Heritage Fund	Funds projects that connect people and communities to the national, regional and local heritage of the UK.
Charles Hayward Foundation	Heritage and Conservation - purchase or reclamation of land for the purposes of creating a nature reserve to be maintained in perpetuity.
John Ellerman Foundation	Certain species and habitats of national significance, protecting the seas, will consider applications from organisations based in NI, England or Wales if the work is of UK-wide significance.
Calouste Gulbenkian Foundation	Projects to improve the quality of life for all throughout art, charity, science and education. The Foundation is committed to the future, to those most vulnerable, and to the value of culture
Ocean 5	Time-bound efforts involving multiple organizations working toward common policy objectives focused on fisheries management reforms and establishment of MPAs.
Scottishpower Foundation Marine Biodiversity Fund	Finance one multi-year project that contributes to the global objectives of protecting our seas and enhancing marine biodiversity, leaving a positive legacy for future generations.

Resource List

- Handbooks
    - Seagrass restoration to be available in April
    - European Native Oyster Habitat Restoration Handbook for the UK and Ireland
- Carbon stock in the North Sea - Yorkshire Wildlife Trust – available later in the year
- Salt marsh restoration toolkit – Essex Wildlife Trust – available later in the year
- Seagrass Spotter App
- Saltmarsh Management Manual - Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme
- ShoreNI (Ulster Wildlife) – iNaturalist app

Recommended Action Plan for Blue Carbon Restoration in Northern Ireland

11. Develop a baseline inventory of all blue carbon habitats (Table 30 below) in Northern Ireland: their extent, with local measurement of carbon sequestration rates (CSRs) and estimated total carbon storage by habitat, including understanding how the condition of habitat affects CSR.

Table 30. Blue carbon habitat in Northern Ireland's waters: pink = intertidal, grey = intertidal and subtidal, blue = subtidal. *=Existing priority habitats or species, or pMCZ component habitat.

Marine and coastal habitats:
Seagrass beds*
Saltmarshes*
Kelp forest
Blue mussel (*Mytilus edulis*) reefs*
Native/flat oyster (*Ostrea edulis**) reefs
Horse mussel (*Modiolus modiolus*) beds*
Brittlestar beds*
Intertidal macroalgae
Subcanopy algae
Maerl beds*
Sabellaria reefs*
Sediments- muds, gravels, sands*

12. Review coastal blue carbon habitat current extent and predicted suitability via additional surveys/ground-truthing, where possible identifying habitat condition at each site (which may affect carbon sequestration potential) and any notable local pressures – make use of existing monitoring programmes to gather such data and develop specific surveys for this purpose.
13. Examine historical records (pre 1980) of coastal blue carbon species and habitat extent (e.g. native oyster reefs) and examine how these relate to current habitat suitability models for potentially suitable conditions for these habitats.
14. Implement the five step plan for incorporation of blue carbon protection in existing Marine Protected Areas (see box 1), levering existing policy commitments for this purpose and making MPAs 'climate smart'. Part of this plan would be addressed by steps (1) and (2).
15. Raise awareness of the potential for blue carbon to contribute to Nationally Determined Contributions to greenhouse gas inventory under the Paris Agreement via engagement with policy-makers and the Climate Change Committee.
16. Understand the role of other blue carbon pools, such as sedimentary habitats, within Northern Ireland's waters, and whether these need additional management and protection.
17. Raise public and policy-makers' awareness of blue carbon as a nature-based solution to climate change, including updating the Northern Ireland Marine Plan to strengthen commitment to this approach. Develop a cross-cutting blue carbon strategy that would underpin action to protect, restore, recreate and monitor blue carbon habitats, with priority given to protection and restoration of existing habitats.

18. Identify pilot projects for coastal blue carbon restoration though further development of the blue carbon restoration feasibility GIS (see below), crucially identifying habitat condition and local carbon sequestration rates then prioritising habitats based on their carbon sequestration and storage potential and practicality of restoration actions, exploring the options of co-restoration of habitats, developing partnerships and securing funding. Through this, build capacity locally for blue carbon restoration with flagship local projects to inspire further habitat restoration efforts and demonstrate viability, while also monitoring the co-benefits of habitat restoration such as biodiversity value and erosion protection.
19. Investigate/research the likely response of blue carbon habitats to climate change, especially those coastal habitats that are the current focus for practical restoration.
20. To make the case for restoring coastal blue carbon habitats, ensure a strong understanding (and valuation where possible) of the co-benefits of restoration, such as biodiversity gains, enhancement of other ecosystem services such as flood protection, water quality improvement, and community buy-in/ownership.

Box 1. A five-point plan for improving the protection and effective management of blue carbon ecosystems in MPAs under the CBD in support of the Paris Agreement on climate change (Laffoley, 2020).

1. Recognise the full extent of blue carbon ecosystems present in MPAs
2. Act on operations likely to cause deterioration or disturbance and take the additional management measures needed not to secure blue carbon values of well documented blue carbon ecosystems
3. Map extent and quality of the carbon value of less well documented carbon ecosystems within current MPAs and implement relevant management measures
4. Designate new MPA based primarily on the carbon values for blue carbon ecosystems that lie outside existing MPAs rather than just focusing on traditional biodiversity value alone
5. Take measures to complement the MPAs using tool such as MSP and fisheries management to recognise, protect and best manage blue carbon across seascapes

Recommendations for the blue carbon restoration feasibility Geographical Information System (GIS):

- A master blue carbon feasibility GIS of the existing extent and habitat suitability layers should attribute existing extent records with information on the habitat patch current condition or population status (where this information exists, or from additional surveys);
- The GIS should include pressure layers (where data are available) and existing designations/protected sites. Predation data, if available, should also be included for shellfish reefs in addition to human pressures;
- The GIS could include spatial surfaces available from UK Climate Projections (UKCP) 2018 and the National Trust 'Future Coast' GIS data to examine the areas that are most vulnerable to climate change which can be used to target restoration efforts;
- The GIS should incorporate local hydrodynamic or coastal process models where available to provide information on suitability of sites for restoration (e.g. seagrass seeding, sediment deposition and erosion regimes).

Technical modelling recommendations:

- Identify saltmarsh habitat outside Strangford Lough to provide additional current extent data that can be used for model training;
- Consider changing the buffer size for each species or habitat record to re-run the model – currently one buffer value was applied to all species/habitats studied;
- Consider using percentiles to set thresholds to explore final maps of habitat suitability
- Cross-reference the value ranges of environmental (predictor) variables associated with suitable habitat with other published values (e.g. MMO 2019a);
- Investigate the impact of riverine inputs on the distribution of seagrass and saltmarsh (via ground-truthing the habitat suitability maps and potentially by inclusion in the modelling process).

Seagrass specific restoration recommendations:

- Fully understand local conditions and pressures prior to selecting a restoration site, including sediment type (<57% silt and clay content, and not too much gravel), proximity to shellfish reefs that may improve local conditions (e.g. via improving water quality);
- At a localised spatial scale, replicate planting in plots at (for example) different depths or elevations, over tens to hundreds of meters, which can mitigate against localised variation in habitat condition whereas variation in choice of habitat type (e.g. variation is sediment type, hydrodynamic regime) can improve success at a kilometre scale;
- Try staggered planting between years or on different dates throughout a planting season within a year can mitigate against stochastic events such as storms. This approach to 'spreading risk' implies a requirement for large scale restoration;
- Optimise techniques to account for ecosystem engineering effects of seagrass. For example, anchoring techniques or the use of biodegradable matting/hessian bags can facilitate plant establishment and promote sediment stabilisation especially in areas with bioturbators such as the lugworm *Arenicola marina;*
- Commit to long-term monitoring as recovery of below-ground biomass could take between 4-6 years.

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Appendix

Table A1. Model perfomances metrics

Species/Habitat	R^2	OOB error
Laminaria digitata	0.75	0.06
Laminaria hyperborea	0.69	0.08
Mytilus edulis	0.48	0.09
Ostrea edulis	0.88	0.00
Saccharina latissima	0.67	0.08
Zostera marina	0.77	0.05
Zostera noltei	0.88	0.01
Saltmarsh	0.21	0.05

Suitable Environmental value ranges for all variables used in each model

Table B1. Environmental value ranges associated with high habitat suitability for *Laminaria digitata*.

Variable	Minimum	Maximum	Mean	SD
Aspect	5.51	317.08	161.20	38.88
Bathymetry	-11.06	-0.54	-5.80	2.65
Current	21.97	1027.99	525.08	206.63
Curvature planform	-0.27	0.28	0.00	0.16
Curvature total	-0.36	0.87	0.25	0.19
Hard/soft substrate	0.01	0.97	0.49	0.07
Maximum sea temperature	12.58	14.22	13.40	0.31
Mean temperature	10.49	10.97	10.73	0.20
Nitrates concentration	0.00	0.42	0.21	0.11
PAR at seabed	1.14	23.91	12.50	3.00
Salinity	31.38	34.06	32.71	0.93
Slope	0.44	11.49	5.95	8.45
EMODnet substrate	1.29	10.78	6.03	1.24
Wave kinetic energy	47.06	3820.23	1935.59	1322.64

Table B2. Environmental value ranges associated with medium habitat suitability for *Laminaria digitata*.

Variable	Minimum	Maximum	Mean	SD
Aspect	1.59	348.99	175.25	20.69
Bathymetry	-14.39	0.35	-7.01	2.71
Current	8.27	1248.28	627.94	83.76
Curvature planform	-0.44	0.62	0.09	0.08
Curvature total	-1.00	1.14	0.07	0.16
Hard/soft substrate	0.00	0.99	0.50	0.03
Maximum sea temperature	12.52	14.83	13.67	0.33
Mean temperature	10.42	11.22	10.82	0.13
Nitrates concentration	-0.01	0.56	0.27	0.05
PAR at seabed	0.50	25.71	13.10	1.81
Salinity	30.31	34.32	32.31	0.55
Slope	0.18	43.87	22.02	9.05
EMODnet substrate	1.03	11.79	6.41	0.49
Wave kinetic energy	24.40	5170.79	2598.30	920.45

Table B3. Environmental value ranges associated with high habitat suitability for *Laminaria hyperborea*.

Variable	Minimum	Maximum	Mean	SD
Wave kinetic energy	47.06	3820.23	1935.59	1322.64
Aspect	9.07	307.87	158.67	40.95
Bathymetry	-18.06	-1.81	-9.90	5.00
Current	40.35	1185.17	613.84	201.70
Curvature planform	-0.30	0.35	0.03	0.12
Curvature profile	-2.67	0.36	-1.16	0.60
Hard/soft substrate	0.07	0.93	0.50	0.13
Mean temperature	10.51	11.01	10.76	0.18
Minimum temperature	7.59	8.36	7.98	0.22
Nitrate concentration	0.00	0.31	0.15	0.06
PAR at seabed	0.49	20.66	10.49	3.41
Salinity	33.14	34.27	33.70	0.36
Slope	1.50	40.91	21.22	9.32
EMODnet substrate	4.06	10.77	7.43	1.80
Wave kinetic energy	15.18	826.85	421.09	353.68

Table B4. Environmental value ranges associated with medium habitat suitability for *Laminaria hyperborea*.

Variable	Minimum	Maximum	Mean	SD
Aspect	2.45	344.23	173.52	24.11
Bathymetry	-28.02	0.11	-13.98	10.65
Current	20.39	1325.51	673.39	96.73
Curvature planform	-0.47	0.47	0.00	0.08
Curvature profile	-3.18	0.84	-1.17	0.33
Hard/soft substrate	0.02	0.98	0.50	0.07
Mean temperature	10.43	11.16	10.79	0.15
Minimum temperature	7.06	8.44	7.75	0.25
Nitrate concentration	-0.02	0.35	0.17	0.04
PAR at seabed	0.40	24.00	12.18	2.46
Salinity	32.04	34.36	33.20	0.30
Slope	0.81	49.58	25.21	5.88
EMODnet substrate	1.71	11.61	6.66	1.06
Wave kinetic energy	6.53	2108.63	1057.39	354.99

Table B5. Environmental value ranges associated with high habitat suitability for *Mytilus edulis*.

Variable	Minimum	Maximum	Mean	SD
Aspect	5.27	347.28	176.19	24.20
Bathymetry	-30.10	2.42	-13.91	26.44
Current	6.33	830.94	418.59	119.75
Curvature planform	-0.43	0.64	0.10	0.09
Curvature profile	-0.71	1.24	0.27	0.12
Distance To Mussels farms	95265.46	2768654.12	1437056.84	599036.35
Hard/soft substrate	0.00	1.00	0.50	0.03
Mean temperature	9.52	10.87	10.19	0.29
Minimum temperature	6.14	8.29	7.21	0.39
Slope	0.16	6.76	3.49	4.21
Temperature in summer	12.54	15.95	14.25	0.57
EMODnet substrate	1.12	10.91	6.01	0.71
Wave kinetic energy	6.46	6486.60	3247.49	968.31

Table B6. Environmental value ranges associated with medium habitat suitability for *Mytilus edulis*.

Variable	Minimum	Maximum	Mean	SD
Aspect	1.74	356.20	178.89	15.26
Bathymetry	-45.41	2.74	-21.39	29.92
Current	1.82	903.73	452.69	73.73
Curvature planform	-0.47	0.66	0.09	0.06
Curvature profile	-0.73	1.28	0.28	0.08
Distance To Mussels farms	29220.04	3310463.46	1676279.55	298057.86
Hard/soft substrate	0.00	1.00	0.50	0.00
Mean temperature	9.32	10.96	10.13	0.17
Minimum temperature	5.90	8.51	7.20	0.22
Slope	0.08	15.36	7.84	4.72
Temperature in summer	12.30	16.42	14.36	0.37
EMODnet substrate	1.02	11.59	6.30	0.54
Wave kinetic energy	1.02	6847.97	3424.55	644.93

Table B7. Environmental value ranges associated with high habitat suitability for *Ostrea edulis.*

Variable	Minimum	Maximum	Mean	SD
Aspect	0.00	360.00	180.00	0.00
Bathymetry	-51.34	5.80	-22.77	0.00
Current	0.34	1268.59	634.46	79.84
Curvature planform	-0.37	1.07	0.35	0.00
Curvature profile	-0.96	1.07	0.05	0.01
Distance To Oyster farms	1345.38	3565004.71	1783172.71	6401.69
Hard/soft substrate	0.00	0.49	0.25	0.00
Mean temperature	10.04	11.05	10.54	0.00
Salinity	28.17	33.75	30.96	0.02
Slope	0.00	27.31	13.66	0.48
Temperature in Spring	8.79	11.40	10.10	0.08
EMODnet substrate	1.00	9.99	5.50	0.07
Wave kinetic energy	0.00	7102.00	3551.00	0.00

Table B8. Environmental value ranges associated with medium habitat suitability for *Ostrea edulis*.

Variable	Minimum	Maximum	Mean	SD
Aspect	0.00	360.00	180.00	0.00
Bathymetry	-51.34	5.80	-22.77	0.26
Current	0.34	1297.54	648.94	16.03
Curvature planform	-0.37	1.07	0.35	0.01
Curvature profile	-0.96	1.07	0.05	0.01
Distance To Oyster farms	1345.38	3565185.00	1783265.19	0.00
Hard/soft substrate	0.00	0.49	0.25	0.00
Mean temperature	10.04	11.05	10.54	0.00
Salinity	28.17	34.02	31.10	0.02
Slope	0.00	27.34	13.67	0.28
Temperature in Spring	8.47	11.40	9.93	0.01
EMODnet substrate	1.00	10.00	5.50	0.03
Wave kinetic energy	0.00	7102.00	3551.00	0.00

Table B9. Environmental value ranges associated with high habitat suitability for *Saccharina latissima*.

Variable	Minimum	Maximum	Mean	SD
Aspect	7.07	327.36	167.03	24.91
Bathymetry	-13.80	-0.95	-7.37	3.16
Current	20.28	1143.78	581.85	210.04
Curvature planform	-0.22	0.39	0.08	0.12
Curvature profile	-0.87	0.41	-0.23	0.17
Hard/soft substrate	0.01	0.98	0.49	0.06
Mean temperature	10.48	11.06	10.77	0.17
Nitrates concentration	0.00	0.45	0.23	0.12
PAR at seabed	0.83	23.58	12.18	2.64
Roughness or rugosity	0.37	20.52	10.43	10.07
Salinity	30.08	34.12	32.09	0.86
Temperature in summer	12.27	14.57	13.42	0.56
EMODnet substrate	1.20	11.50	6.33	0.80
Wave kinetic energy	37.85	3664.56	1852.44	1622.26

Table B10. Environmental value ranges associated with medium habitat suitability for *Saccharina latissima*.

Variable	Minimum	Maximum	Mean	SD
Aspect	5.25	349.25	177.13	22.18
Bathymetry	-19.09	0.07	-9.50	4.06
Current	8.43	1305.56	657.10	106.87
Curvature planform	-0.47	0.62	0.08	0.07
Curvature profile	-1.03	0.63	-0.20	0.11
Hard/soft substrate	0.00	1.00	0.50	0.03
Mean temperature	10.42	11.22	10.82	0.12
Nitrates concentration	-0.02	0.62	0.30	0.07
PAR at seabed	0.33	24.99	12.66	1.85
Roughness or rugosity	0.28	42.44	21.36	8.07
Salinity	29.48	34.33	31.90	0.44
Temperature in summer	12.15	15.20	13.67	0.49
EMODnet substrate	1.06	11.86	6.45	0.54
Wave kinetic energy	9.99	6163.60	3087.92	1137.69

Table B11. Environmental value ranges associated with high habitat suitability for saltmarsh.

Variable	**Minimum**	**Maximum**	**Mean**	**SD**
Aspect	0.89	77.65	37.98	32.67
Bathymetry	0.43	2.30	1.37	0.31
Coastal Erosion	-12.21	-9.10	-10.74	1.39
Curvature planform	-0.01	0.55	0.27	0.36
Curvature total	-0.36	-0.05	-0.20	0.27
Hard/soft substrate	0.00	0.57	0.28	0.10
Slope	0.40	1.07	0.67	0.27

Table B12. Environmental value ranges associated with medium habitat suitability for saltmarsh.

Variable	**Minimum**	**Maximum**	**Mean**	**SD**
Aspect	14.02	242.82	128.27	74.10
Bathymetry	-1.27	15.41	7.07	8.09
Coastal Erosion	-12.32	-5.48	-9.05	2.73
Curvature planform	-0.69	1.27	0.29	0.30
Curvature total	-1.56	0.62	-0.47	0.81
Hard/soft substrate	0.02	0.79	0.41	0.14
Slope	0.47	6.43	3.45	8.24

Table B13. Environmental value ranges associated with high habitat suitability for *Zostera marina*.

Variable	Minimum	Maximum	Mean	SD
Aspect	6.11	349.67	177.89	14.27
Bathymetry	-37.08	-0.04	-18.56	17.02
Current	3.96	1257.71	630.84	167.22
Curvature planform	-0.46	0.51	0.02	0.06
Curvature total	-1.33	3.73	1.20	0.28
Hard/soft substrate	0.00	0.98	0.49	0.05
Mean temperature	10.47	10.99	10.73	0.13
Nitrates concentration	0.00	0.41	0.21	0.05
PAR at seabed	2.43	25.63	14.03	2.52
Salinity	29.58	34.25	31.91	0.17
Slope	0.04	39.96	20.00	10.96
Temperature in summer	12.33	14.93	13.51	0.67
EMODnet substrate	1.86	11.01	6.35	1.56
Wave kinetic energy	20.62	2116.79	1068.50	388.11

Table B14. Environmental value ranges associated with medium habitat suitability for *Zostera marina*.

Variable	Minimum	Maximum	Mean	SD
Aspect	9.34	349.04	179.19	31.90
Bathymetry	-63.99	-0.41	-32.19	12.50
Current	4.69	1315.70	660.19	102.03
Curvature planform	-0.48	0.50	0.01	0.05
Curvature total	-1.45	3.63	1.09	0.32
Hard/soft substrate	0.00	0.99	0.50	0.04
Mean temperature	10.39	11.03	10.71	0.06
Nitrates concentration	-0.02	0.41	0.20	0.04
PAR at seabed	0.90	25.06	12.93	2.53
Salinity	29.73	34.34	32.02	0.44
Slope	0.04	49.89	24.97	6.03
Temperature in summer	12.16	15.50	13.81	0.27
EMODnet substrate	1.27	11.84	6.56	0.87
Wave kinetic energy	19.42	2346.48	1183.39	191.68

Table B15. Environmental value ranges associated with high habitat suitability for *Zostera noltei*.

Variable	**mean(min)**	**sd(min)**	**mean(max)**	**sd(max)**	**mean(mean)**	**sd(mean)**
Aspect	7.52	38.01	356.71	0.00	182.11	19.00
Bathymetry	-24.60	31.15	0.09	0.00	-12.26	15.58
Current	0.34	0.00	1321.32	214.22	660.83	107.11
Curvature planform	-0.49	0.00	0.51	0.07	0.01	0.04
Curvature profile	-3.27	0.52	1.38	0.00	-0.95	0.26
Hard/soft substrate	0.00	0.00	0.99	0.08	0.49	0.04
Mean temperature	10.39	0.00	11.05	0.00	10.72	0.01
Nitrates concentration	0.39	0.08	0.41	0.00	0.40	0.03
PAR at seabed	0.28	1.79	24.40	0.00	12.34	0.90
Salinity	29.58	0.00	33.97	0.49	31.77	0.25
Slope	0.00	0.00	50.35	11.33	25.17	5.67
Temperature in Spring	8.54	0.27	11.39	0.00	9.96	0.14
EMODnet substrate	1.13	0.79	6.83	1.48	3.98	0.81
Wave kinetic energy	0.61	3.88	2374.26	357.16	1187.43	176.64

Table B16. Environmental value ranges associated with high habitat suitability for *Zostera noltei*.

Variable	**mean(min)**	**sd(min)**	**mean(max)**	**sd(max)**	**mean(mean)**	**sd(mean)**
Aspect	1.51	0.00	356.71	0.00	179.11	0.00
Bathymetry	-68.32	20.23	0.09	0.00	-34.11	10.11
Current	0.34	0.00	1355.20	0.00	677.77	0.00
Curvature planform	-0.49	0.00	0.50	0.10	0.00	0.05
Curvature profile	-3.35	0.00	1.38	0.00	-0.99	0.00
Hard/soft substrate	0.00	0.00	1.00	0.00	0.50	0.00
Mean temperature	10.39	0.00	11.05	0.00	10.72	0.00
Nitrates concentration	0.27	0.20	0.41	0.00	0.34	0.10
PAR at seabed	0.60	2.46	24.40	0.00	12.50	1.23
Salinity	29.58	0.00	34.20	0.40	31.89	0.20
Slope	0.00	0.00	49.56	12.99	24.78	6.49
Temperature in Spring	8.63	0.45	11.39	0.00	10.02	0.23
EMODnet substrate	1.11	0.73	11.36	1.87	6.23	0.85
Wave kinetic energy	0.00	0.00	2430.73	0.00	1215.36	0.00

Workshop Participant List

Armagh City, Banbridge, & Craigavon	National Oceanography Centre	Natural Resources Wales
Belfast City	Project Seagrass	Wildfowl and Wetland Trust
CEDaR	Queen's University Belfast	BIC Marine sub group
Climate NI	RSPB - NI	Natural England (ReMEDIES)
Cumbria Wildlife Trust	Scottish Wildlife Trust	GMIT
Department of Agriculture, Environment and Rural Affairs (DAERA)	Sea Wildling	Fingal County Council
Derry City and Strabane	Strangford Lough and Lecale Partnership	Manx Wildlife Trust
Dornach Environmental Enhancement Project	Sussex Wildlife Trust	Natural England (ReMEDIES)
Essex Wildlife Trust	The Wildlife Trusts	GMIT
Fermanagh & Omagh District Council	Ulster Wildlife	Fingal County Council
Heriot Watt University	University of Swansea	Natural Resources Wales
Lisburn & Castlereagh District Council	University of Essex	Wildfowl and Wetland Trust
Lough Swilly Wild Oyster Society	University of Hull	BIC Marine sub group
Loughs Agency	University of Portsmouth	
Manx Wildlife Trust	University of St Andrews	
Marine Institute	ZSL	
Crown Estate	Causeway Coast and Glens District Council	
Marine Scotland	Agri-Food and Biosciences Institute - working with DAERA on coastal erosion	
MarPAMM project	Blue Marine Foundation	
Mid & East Antrim District Council	Manchester Metropolitan University	
National Trust	Belfast Harbour	
Native Oyster Restoration Network	UK Centre for Ecology & Hydrology	

Composite maps combining extent with medium and high habitat suitability

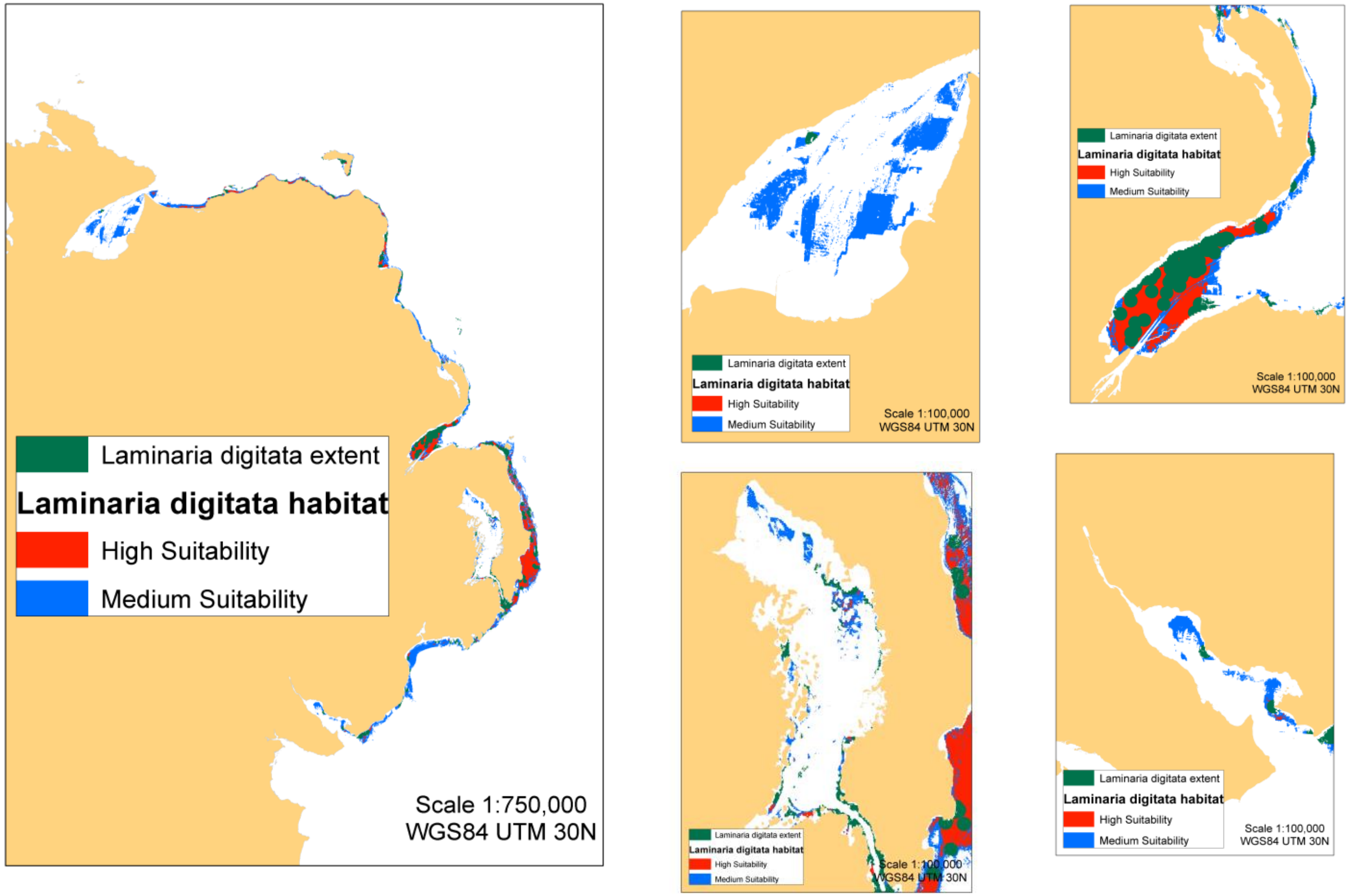


Figure C1. Current extent as well as the predicted distribution of medium and high habitat suitability for *Laminaria digitata* in Northern Ireland.

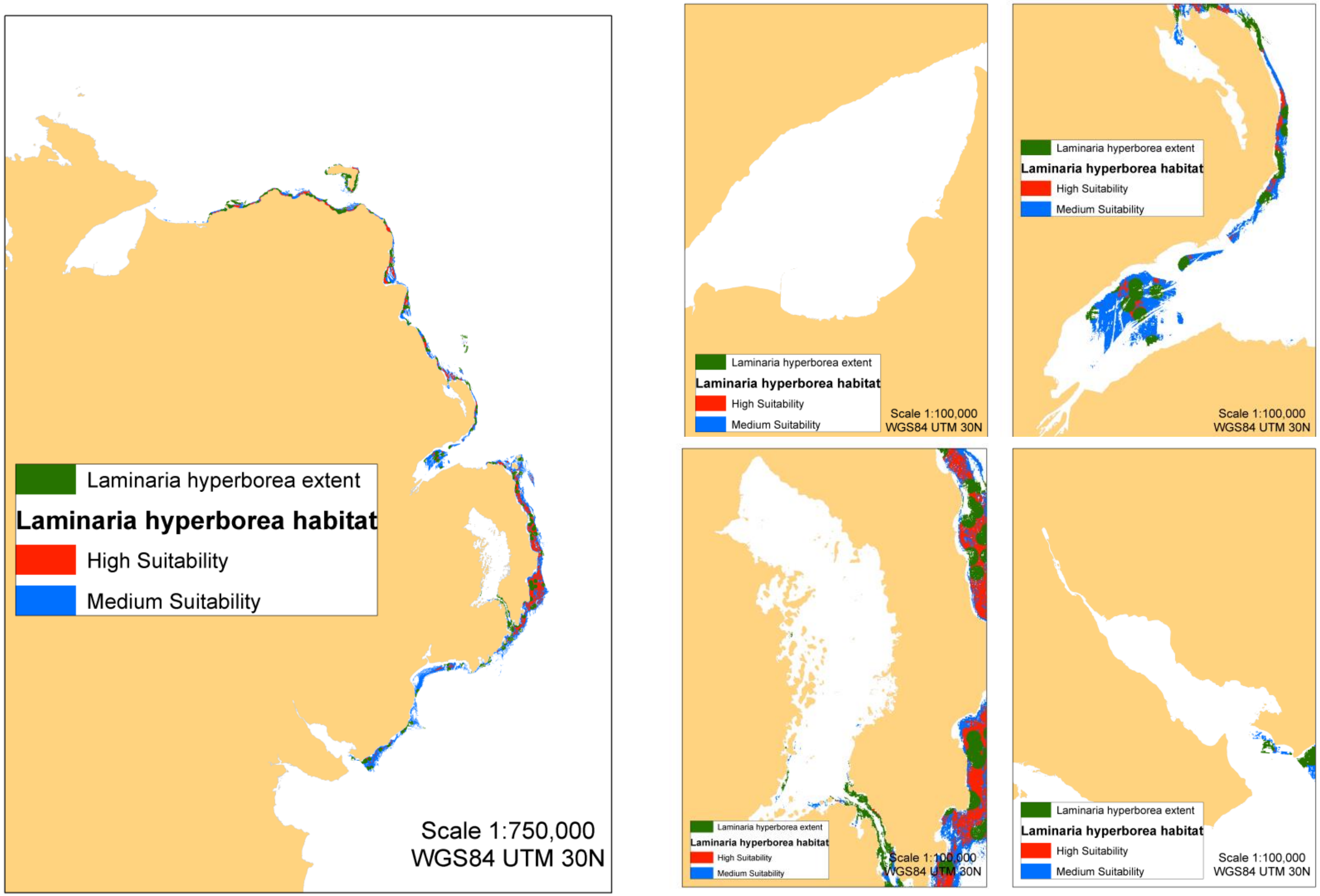


Figure C2. Current extent as well as the predicted distribution of medium and high habitat suitability for *Laminaria hyperborea* in Northern Ireland.

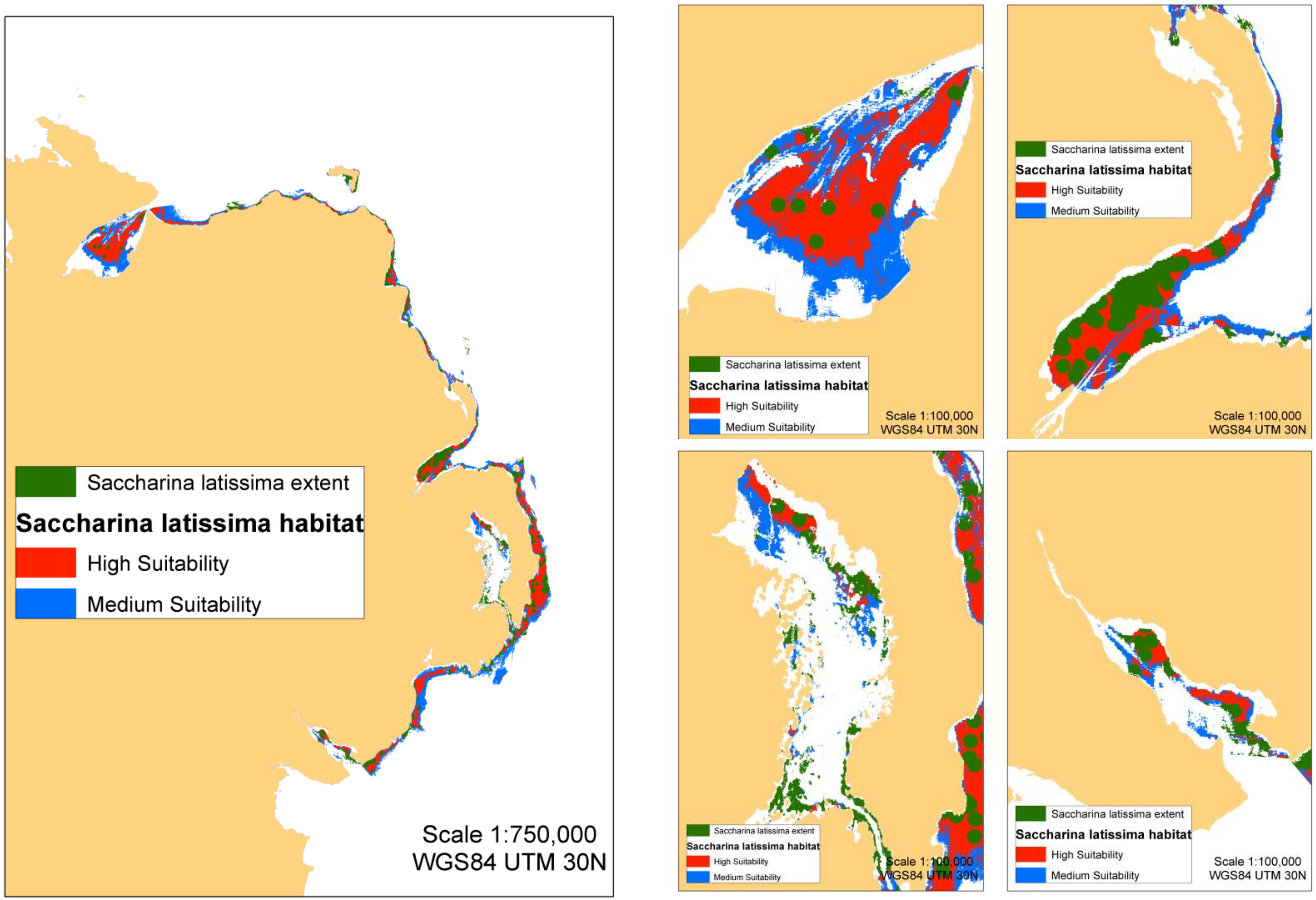


Figure C3. Current extent as well as the predicted distribution of medium and high habitat suitability for *Saccharina latissima* in Northern Ireland.

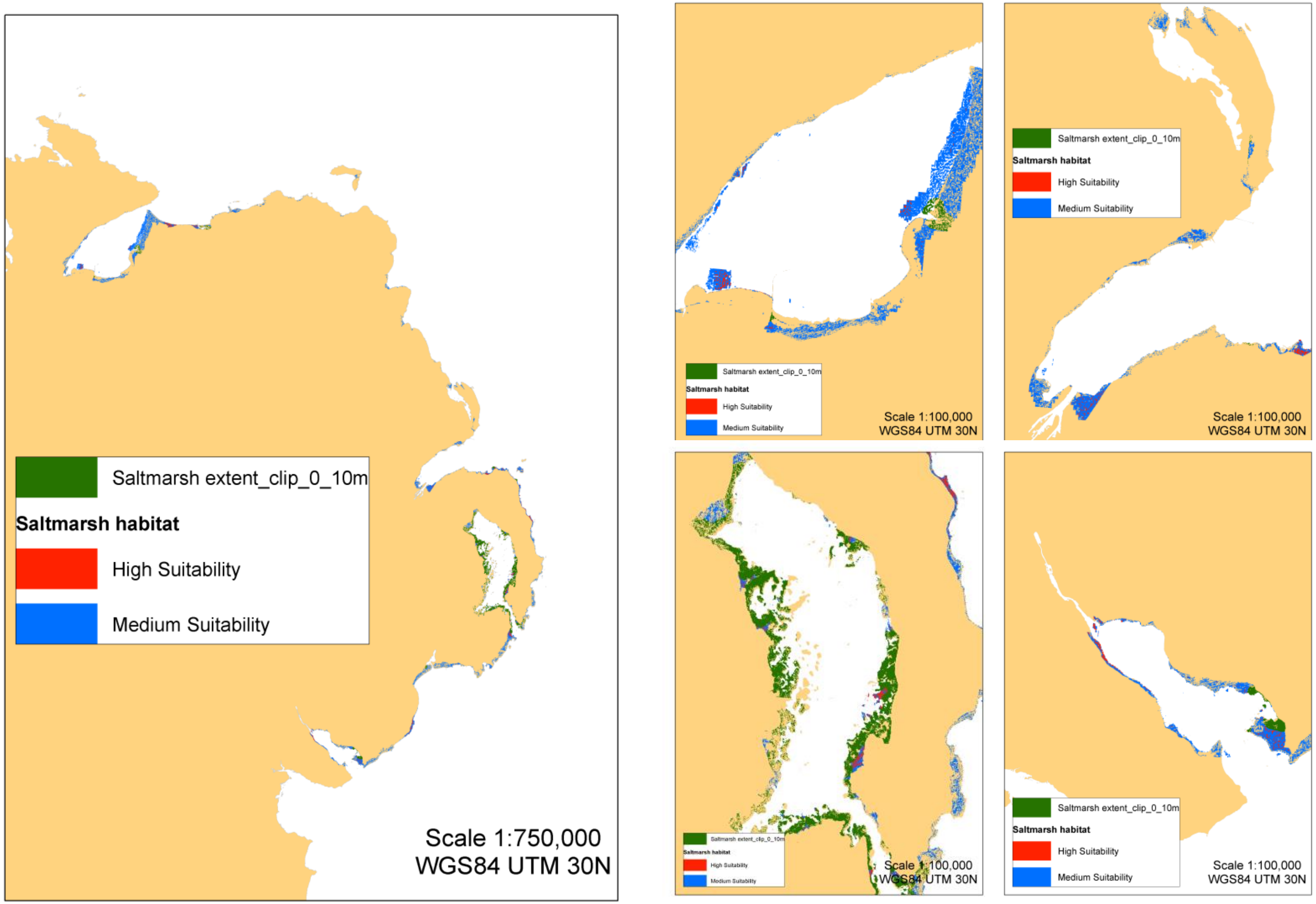


Figure C4. Current extent as well as the predicted distribution of medium and high habitat suitability for Saltmarsh in Northern Ireland.

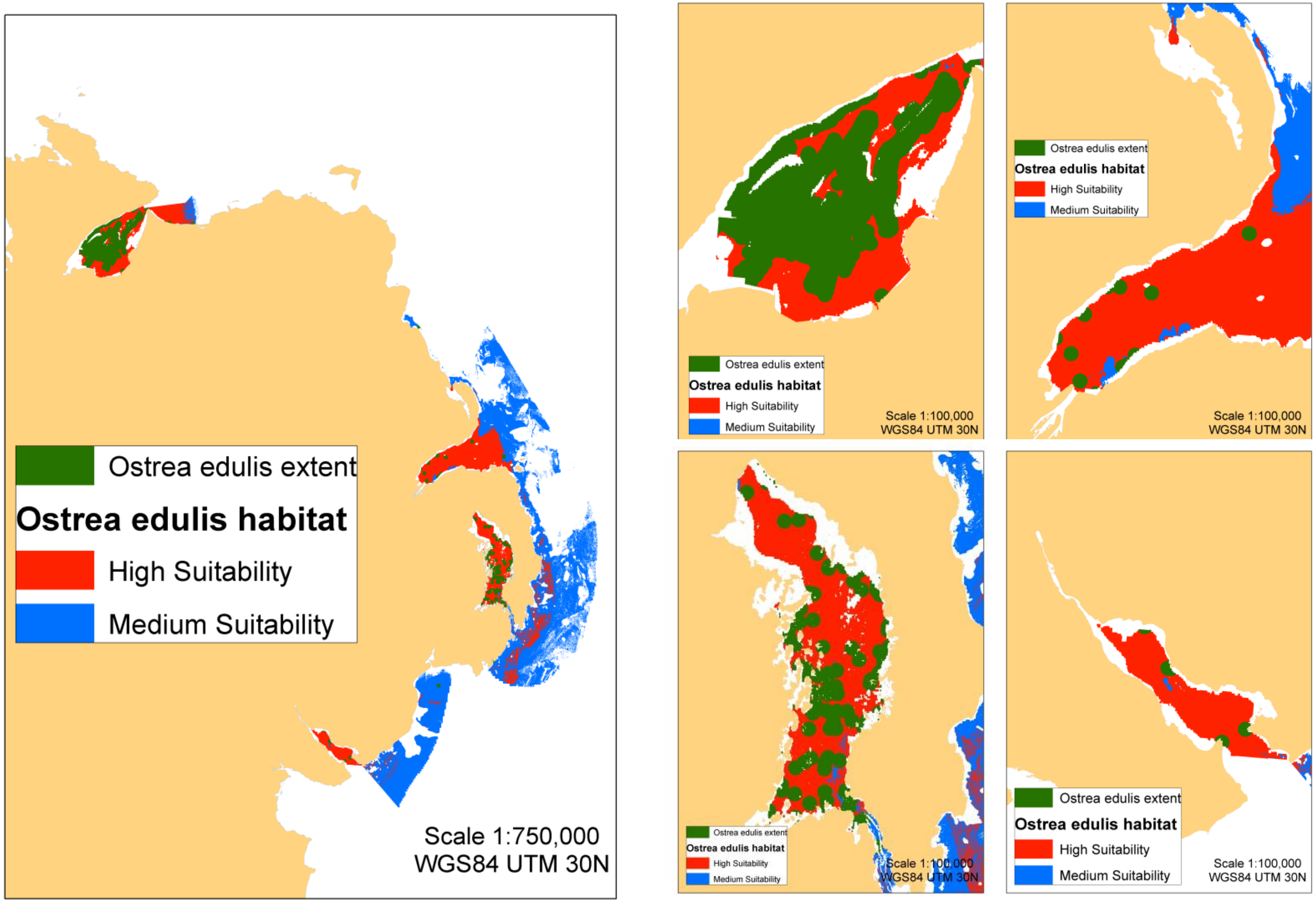


Figure C5. Current extent as well as the predicted distribution of medium and high habitat suitability for *Ostrea edulis* in Northern Ireland.

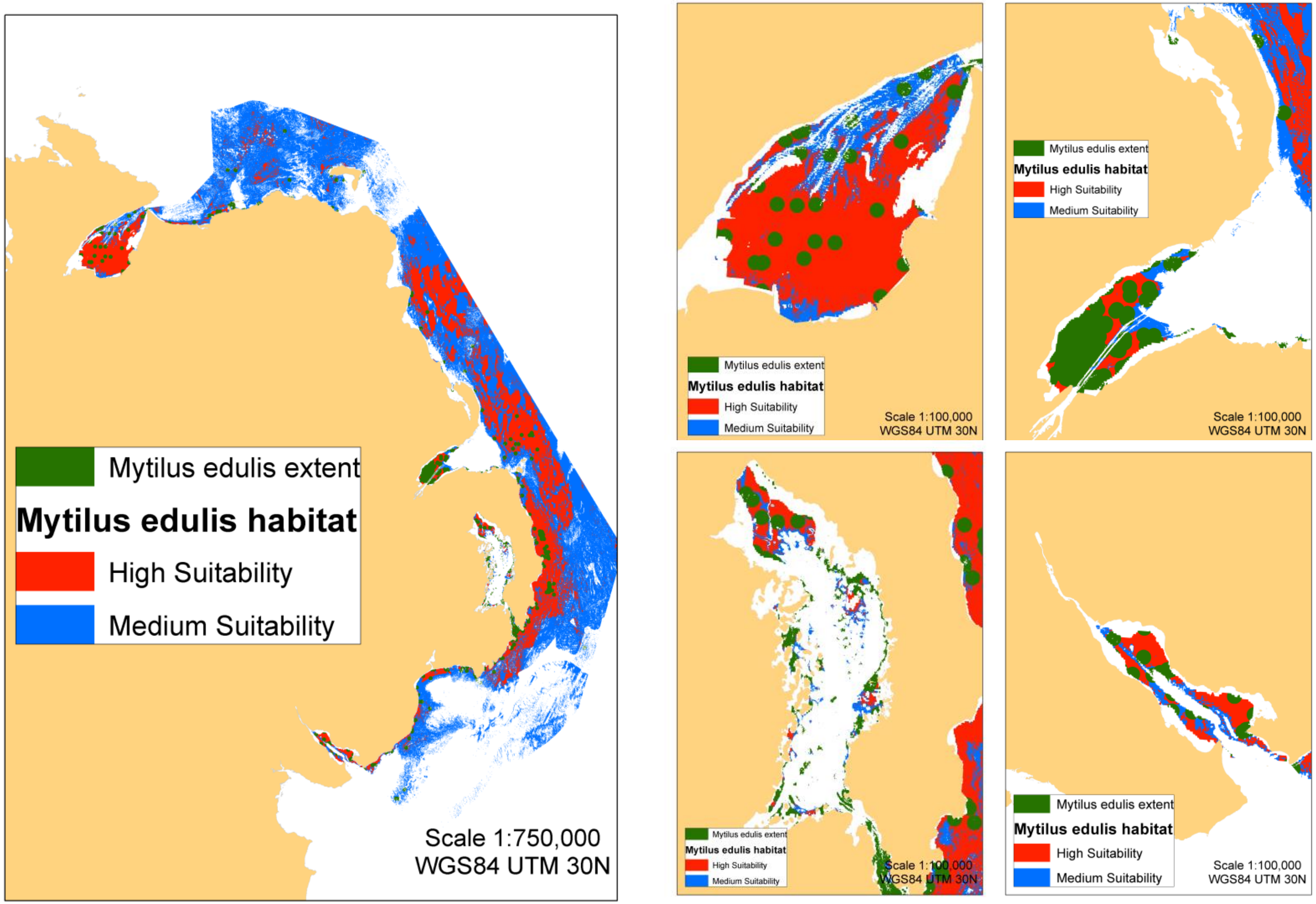


Figure C6. Current extent as well as the predicted distribution of medium and high habitat suitability for *Mytilus edulis* in Northern Ireland.

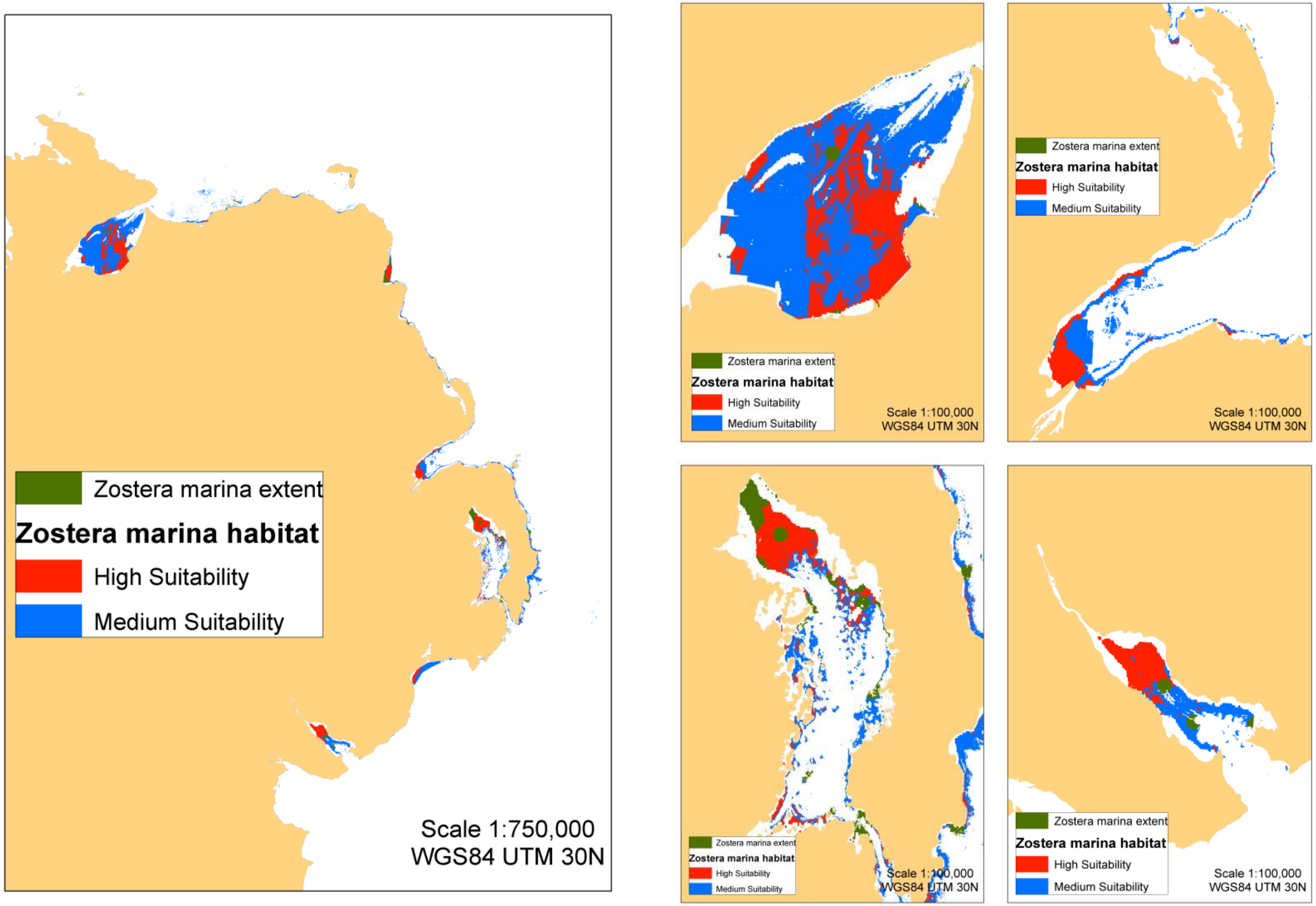


Figure C7. Current extent as well as the predicted distribution of medium and high habitat suitability for *Zostera marina* in Northern Ireland.

Scale of units

Tonnes			Grams			Equivalents	
Symbol	Value	Name	Symbol	Value	Name	Tonnes (t)	Grams (g)
			kg	10^3 g	kilogram	0.001 t	1,000 g
t	10^0 t	tonne	Mg	10^6 g	megagram	1 t	1 million g
kt‡	10^3 t	kilotonne	Gg	10^9 g	gigagram	1,000 t	1 billion g
Mt	10^6 t	megaton	Tg	10^{12} g	teragram	1 million t	1 trillion g
Gt	10^9 t	gigatonne	Pg	10^{15} g	petagram	1 billion t	1 quadrillion g

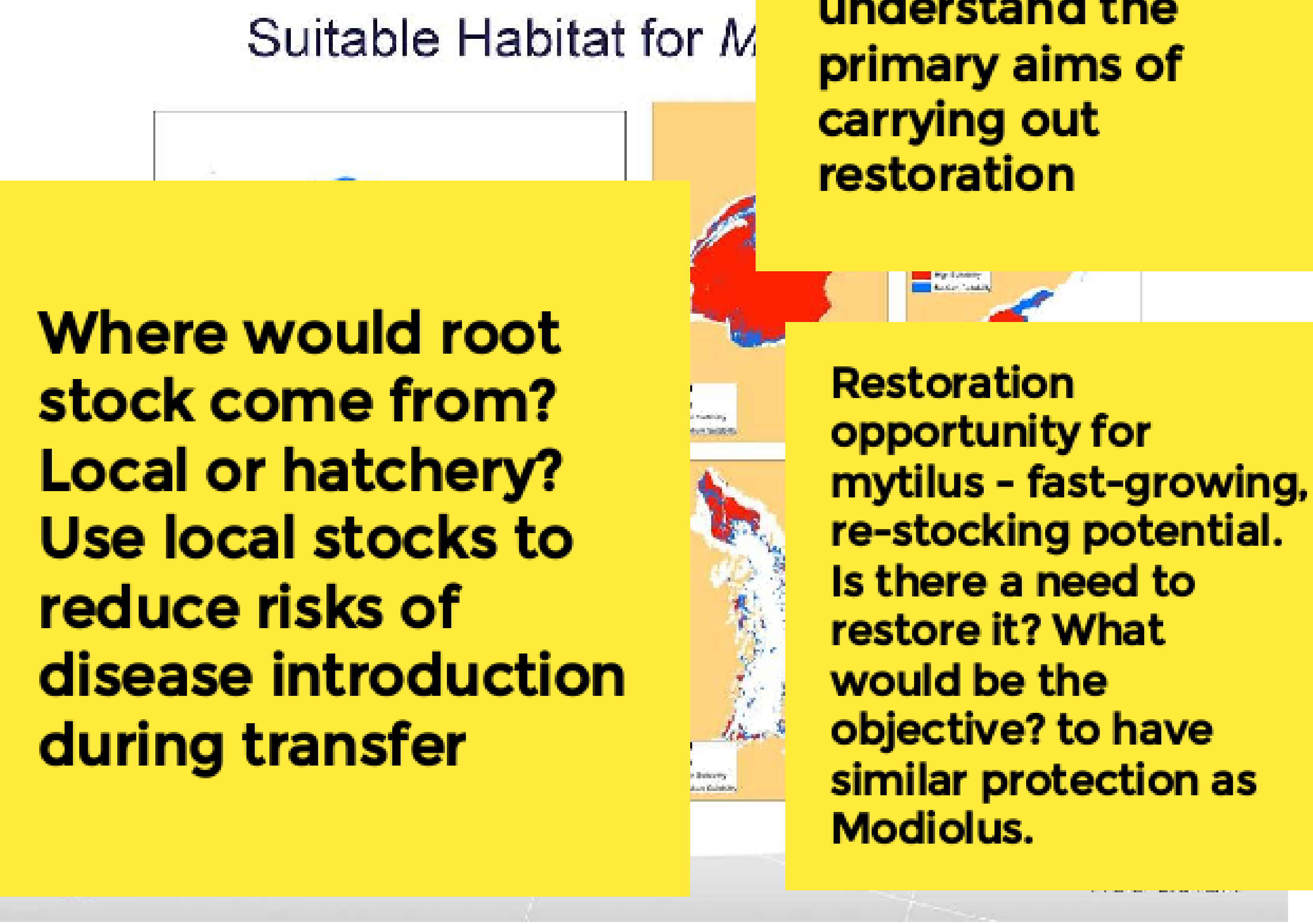
(Cyr^{-1} means carbon sequestered per year, e.g. 27.4 $TgCyr^{-1}$ (million tons of carbon per year))

Jamboards from workshop

Shellfish Restoration

What would this type of restoration look like in NI?
What are the barriers to this type of restoration in NI?
What are the opportunities for this type of restoration in NI?
What pressures need to be limited to achieve this type of restoration in NI?

Restoration for conservation or exploitation? For the purposes of BCarbon - restoration for habitat creation would be the driver - therefore not commercially viable



Where would root stock come from? Local or hatchery? Use local stocks to reduce risks of disease introduction during transfer

Clear potential because of historic evidence of species extents, need to understand the primary aims of carrying out restoration

Restoration opportunity for mytilus - fast-growing, re-stocking potential. Is there a need to restore it? What would be the objective? to have similar protection as Modiolus.

Shellfish Restoration

What would this type of resto
What are the barriers to this
What are the opportunities fo in NI?
What pressures need to be li e of re

on Friday - rational for funding for Foyle funding getting clutch is not easy invasive species and hardening of it is not easy - also working on broodstock augmentation project spatting ponds like huge johnton in Cork - Need Land for

Native Oyster restoration Lough Foyle is happening - Management system- legislation? in place since 2008 before then free for all Previously no minimum landing sizze - now 80mm held in pop long enough to spawn

Issue Recruitment need reliable spatting recruitment every year - that's why season is shortened second spike in summer - more time to harden and resilient to trawling

UCD and Trinity - historical beds fished out and loosing mussel beds too don't want to waste money as people may harvest it all out don't want to waste money - outside harvesting zones eg subtida al - but need more equipment

LEgislation in Lough Foyle can close areas for restoration and close if bed stock drops - do people accept the legislation- LoughsAGENCY HAS ENFORCEMENT REMIT

DISEASE PASSING BETWEEN OYSTER SPECIES BIEMIA Factor into spatting Pond Foyle Oyster not as suseptable as others use local brood stock genetic resilience balance in genetic variability

Also may be genetic inbreeding? Look at modelling - eg IBIS Genetic work Lough Foyle and Lough Ryan? (Lawrence Eagling)

Shellfish Restoration

Non-native species e.g. gigas

restoration versus restorative mariculture

loughs agency - key player on transboundary loughs - opportunity for collaboration and knowledge exchange?

Opportunities maybe not highlighted in presentations. There is a gap in the designation for oysters. Proposals to designate but they are not yet in place due to water borders

barrier because of border disputes, who own Lough Foyle

sustainable fishery model to sell gigas - changing opinions about them as a food source (barrier of peoples taste for them)

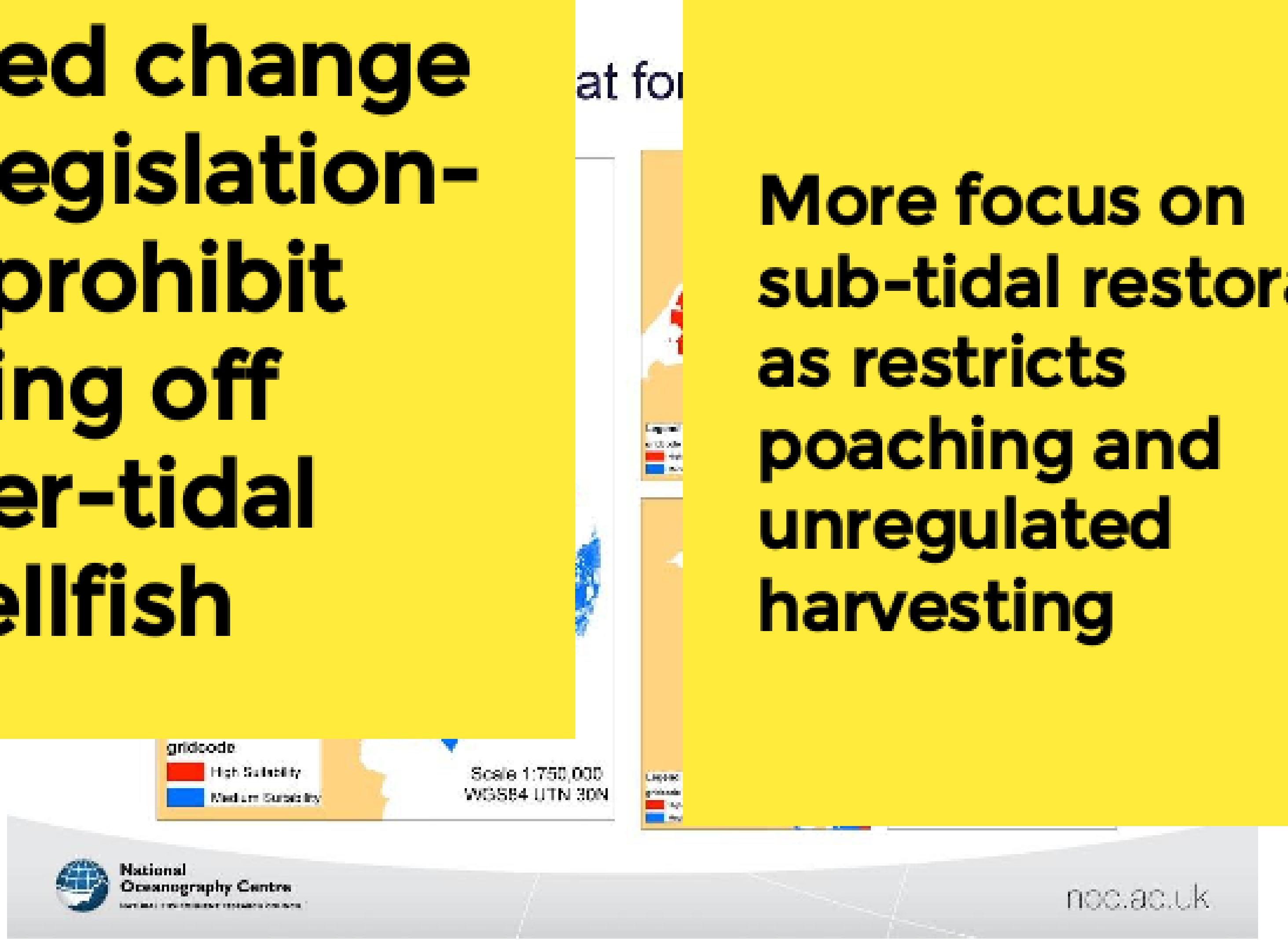
Biosecurity - NORA and NON handbook on biosecurity

permit requirements

set aside a site for oyster in lough foyle that feeds into restoration?

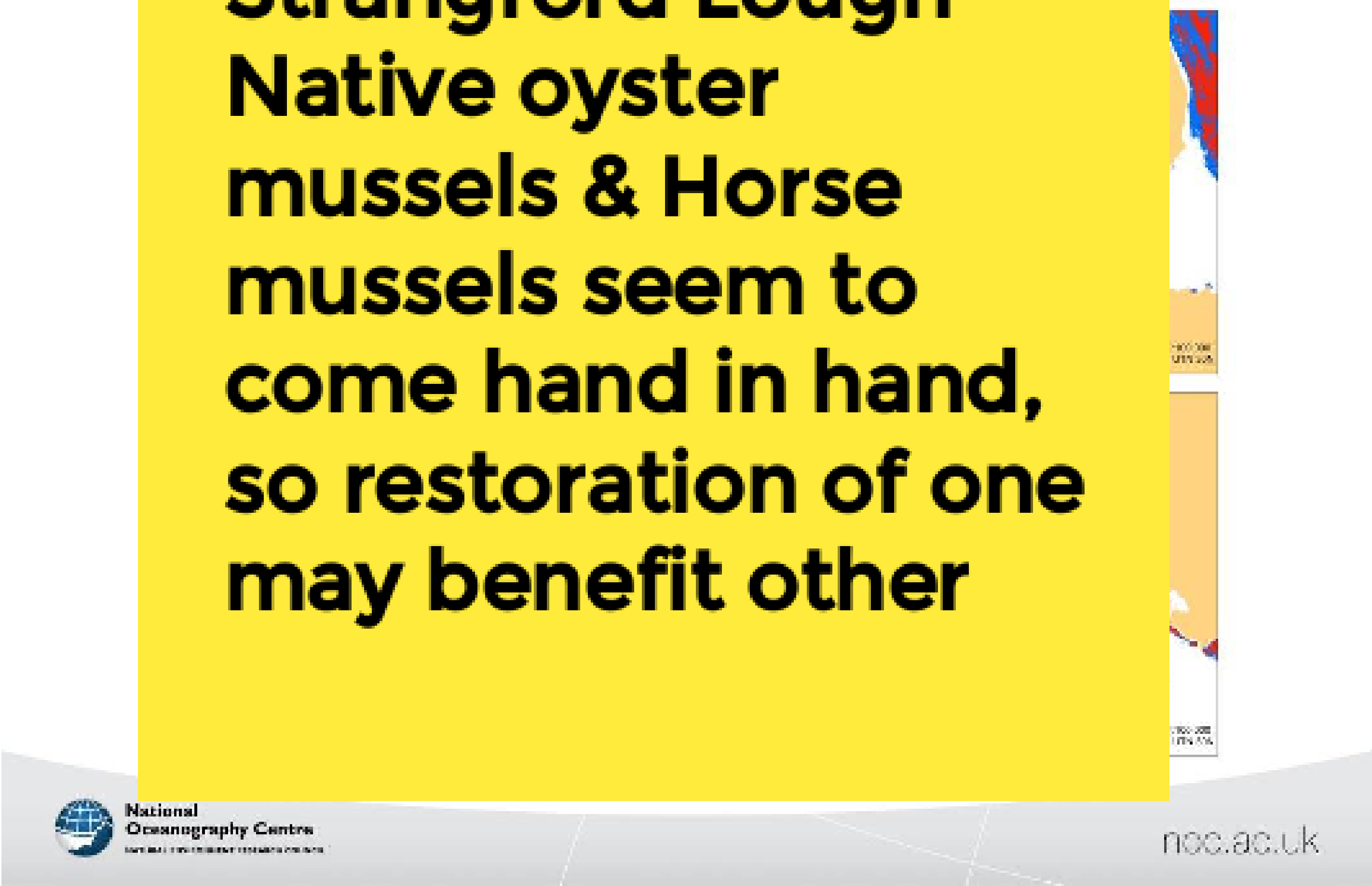
Shellfish Restoration

What would this type of restoration look like in NI?
What are the barriers to this type of restoration in NI?
What are the opportunities for this type of restoration in NI?
What pressures need to be limited to achieve this type of restoration in NI?



Need change in legislation- to prohibit lifting off inter-tidal shellfish

More focus on sub-tidal restoration as restricts poaching and unregulated harvesting



Strangford Lough- Native oyster mussels & Horse mussels seem to come hand in hand, so restoration of one may benefit other

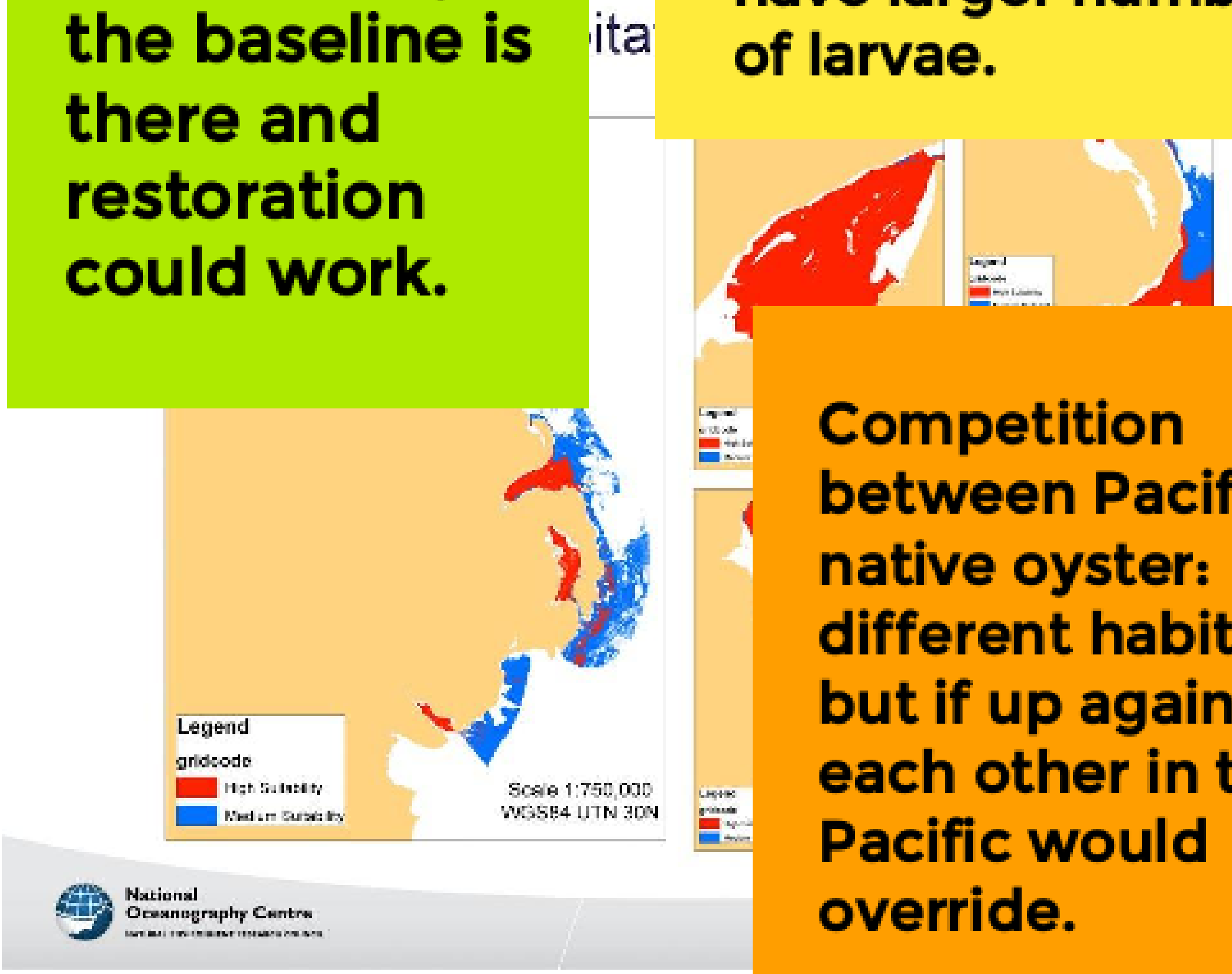
Shellfish Restoration

What would this type of restoration look like in NI?
What are the barriers to this ty… …l?
What are the opportunities for… …n in NI…
What pressures need to be lin… …pe of r…

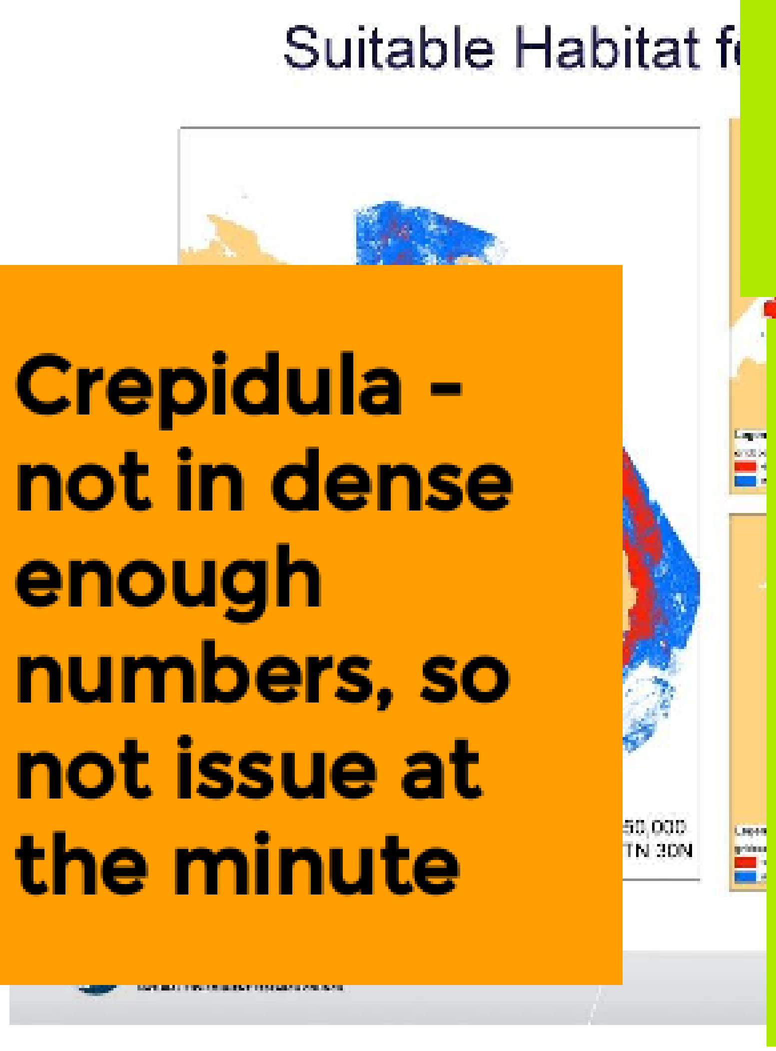
Pressure: Clash between industries re:Blue Carbon? Pacific oysters can overtake native species, as they are more adaptive and have larger number of larvae.

Opportunity (potentially): oyster restoration can fit in within larger ecosystem restoration frameworks (multiple species)

Opportunity: the baseline is there and restoration could work.



Competition between Pacific and native oyster: different habitats, but if up against each other in tank - Pacific would override.



Opportunity: Pacific oysters can provide the same type of ecosystem services. could we use them to restore degraded habitat, for restoring native oysters...?

Crepidula - not in dense enough numbers, so not issue at the minute

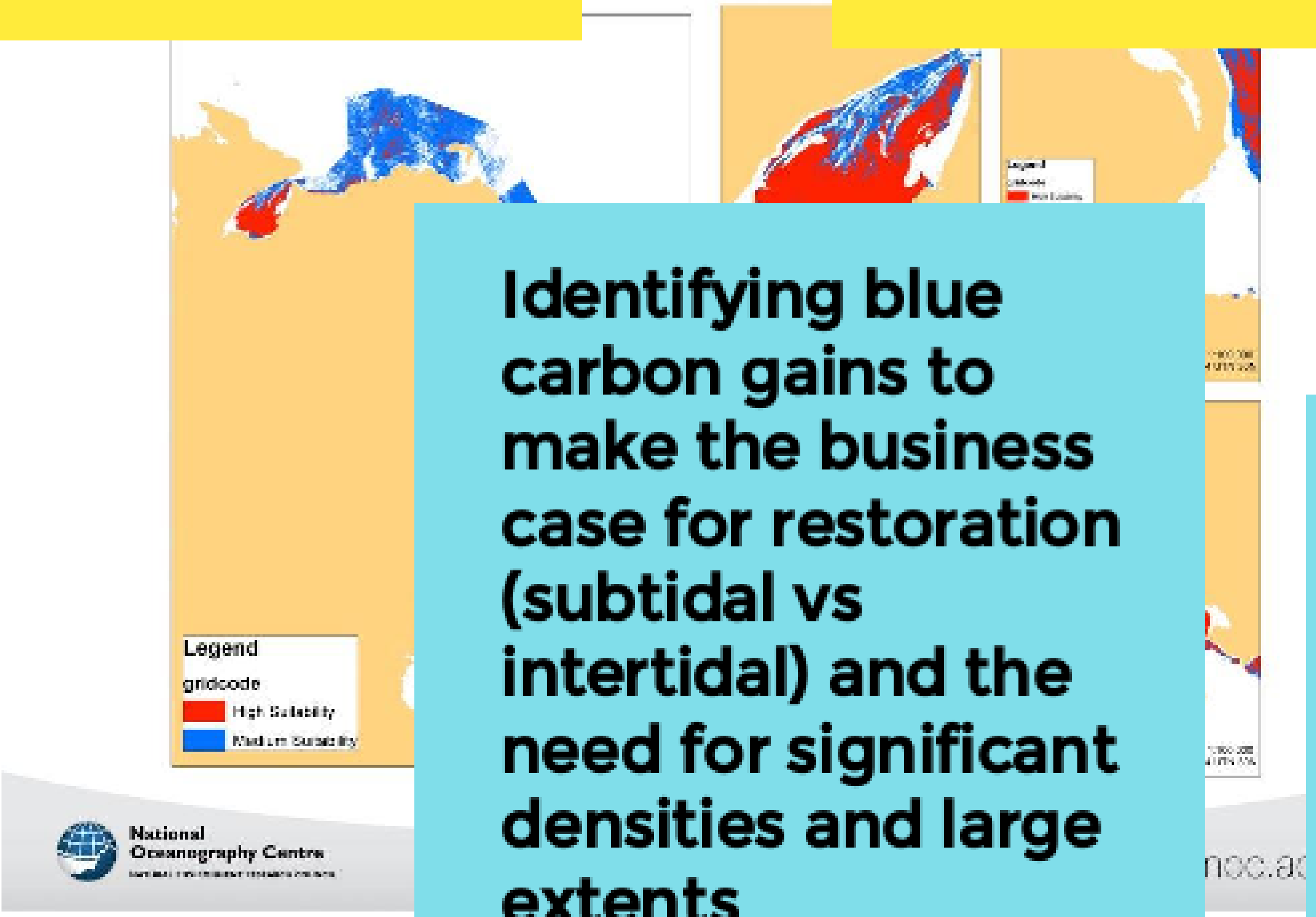
Opportunity: restoration of native oyster shown in Strangford, so lessons learned can be used in other areas.

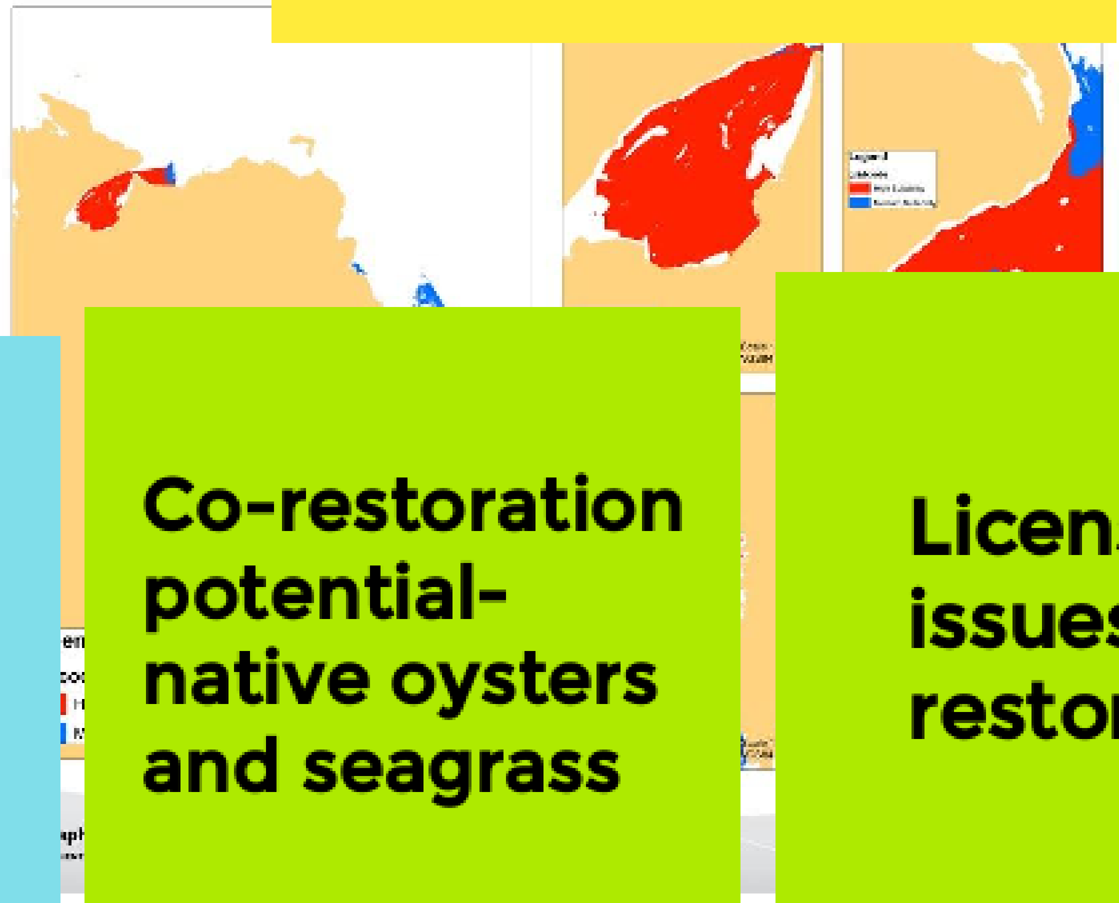
Shellfish Restoration

Supply is a big barrier, but having resident local populations could help (esp Lough Foyle)

Ensure understanding of sediment dynamics/hydrodynamic regime to situate projects

Identifying the policy and business drivers





Identifying blue carbon gains to make the business case for restoration (subtidal vs intertidal) and the need for significant densities and large extents

Issue of disease (and supply of oysters that are disease-free)

Co-restoration potential- native oysters and seagrass

Licensing issues for restoration

Shellfish Restoration

What would this type of restoration look like in NI?
What are the barriers to this type of restoration in NI?
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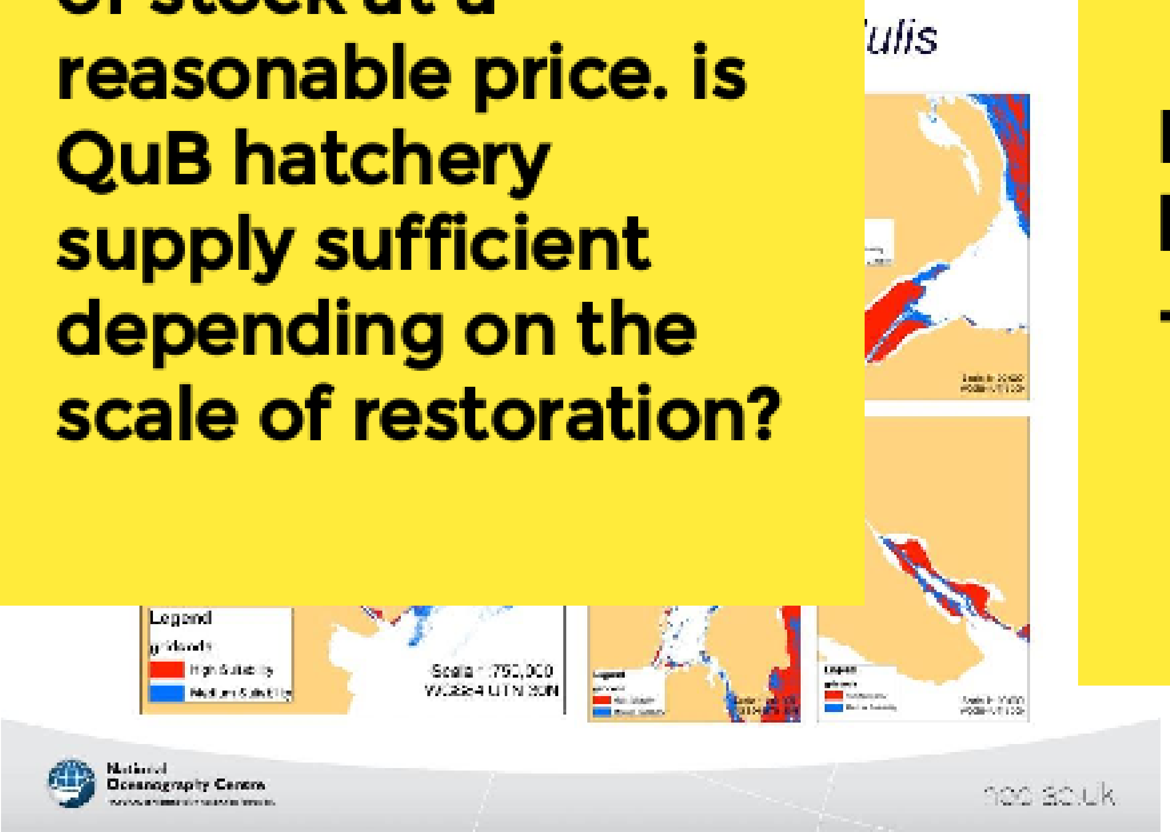
What pressures need to be limited to achieve this type of restoration in NI?

Hatchery - would increasing the size decresase the cost?

Barrier - availability of stock at a reasonable price. is QuB hatchery supply sufficient depending on the scale of restoration?



Barriers - licesing/permissions - costs and time

Kelp Restoration

What would this type of restoration look like in NI?
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What pressures need to be limited to achieve this type of restoration in NI?

limited data on health and extent of bed

Spatial planning - dredging inshore, marine renewables, coastal development

Salmon farming - other impacts

cost of aquaculture - spatial planning issues

climate change - changing range extent

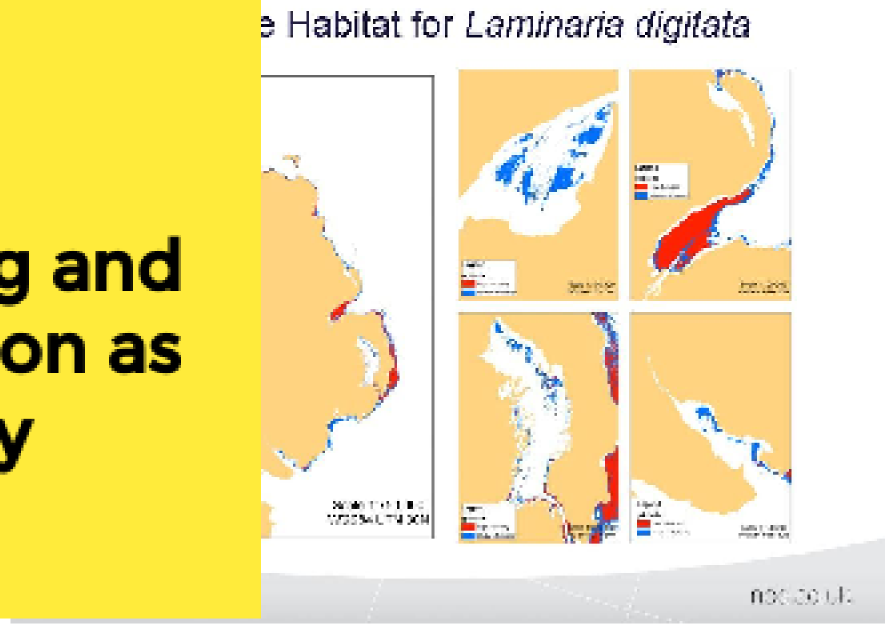
opportunity - no dredging (currently)

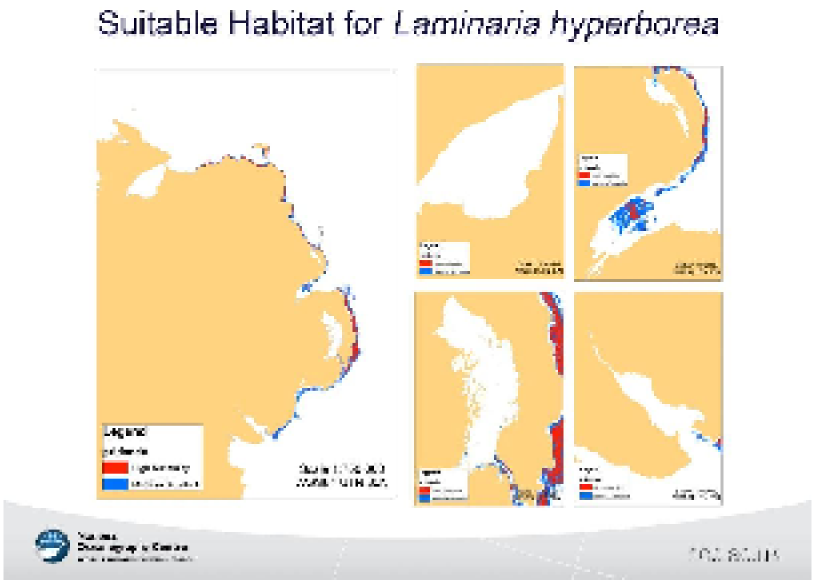
More data needed on field surveying +monitoring etc.

commercial interest in extraction likely to increase

not currently considered in priority/conservation lists

Need mapping and protection as a priority





Saccharina - lots of observations. Growing on aquaculture beds? Maybe a mechanism for restoration - providing substrate (oyster shells etc.)

Kelp not always such a good blue carbon habitat. Provides source of blue carbon to be distriuted elsewhere - often to deep canyons. NI doesn't have these so where will it be stored?

Ocean literacy challenge? Have people heard of kelp and so do they care? Just considered 'seaweed' and a blight becuase of Ulva. Kelp 'forest' helps.

Why is kelp absent from areas the model predict it to occur? Dredging is a big issue. What is the condition of kelp currently and what are the pressures? Is it even a restoration priority?

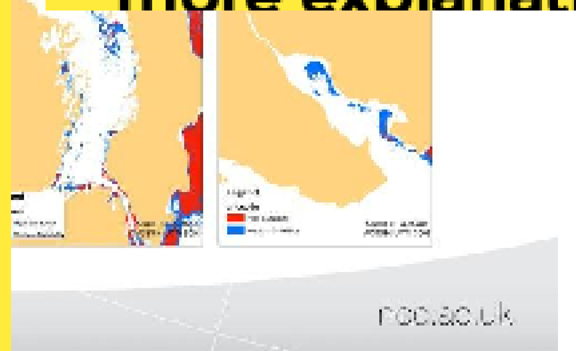
Use historical knowledge to map if kelp is a priority for restoration. Likely better to remove pressures?

Blue carbon often not clearly communicated. Forest has the carbon and we can see the carbon, but in coastal habitats it is buried (not stored in teh plants and so not observed). Timeframes also need more explanation

Local knowledge is really important. Could use seagrass spotter but for kelp? Talk to aquaculture indusrty?

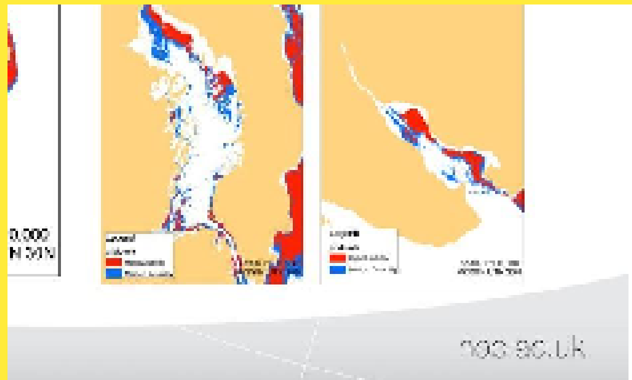
Lots of local expertise in seaweed harvesting at Queens - an opportunity

Some concerns that best blue carbon species are invasive. Need to diversify



Invasive Japanese kelp is moving north. Lots of other invasive species likleyto come

is there any exploitative pressure? There is in Brittany and elsewhere. In Sctland there is interest in coppicing the kelp - but banned currently. Seeding ropes.



Kelp Restora

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issues with harvesting?

opportunites - monitoring, eg look at Stangford / sites where been closed to fishing

education on the value of it as a habitat and blue carbon / ecosystem services

IAS impact issues (invasive alien species)

require baseline data to make informed decision if restoration required and where

H&S issues where kelp removed? Kelp removed from shoreline

reduce pressures on kelp beds, eg trawling

Suitable Habitat for *Saccharina latissima*

Suitable H

opportunities - review historical data

opportunities - education

diving groups - give insight

opportunity to create new habitat???? Or expand the existing sites? Or focus on degrade habs and transplant?

need legislation - help priorities / priority framework?

Kelp Restoration

What would this type of res… l?
What are the barriers to this … n NI
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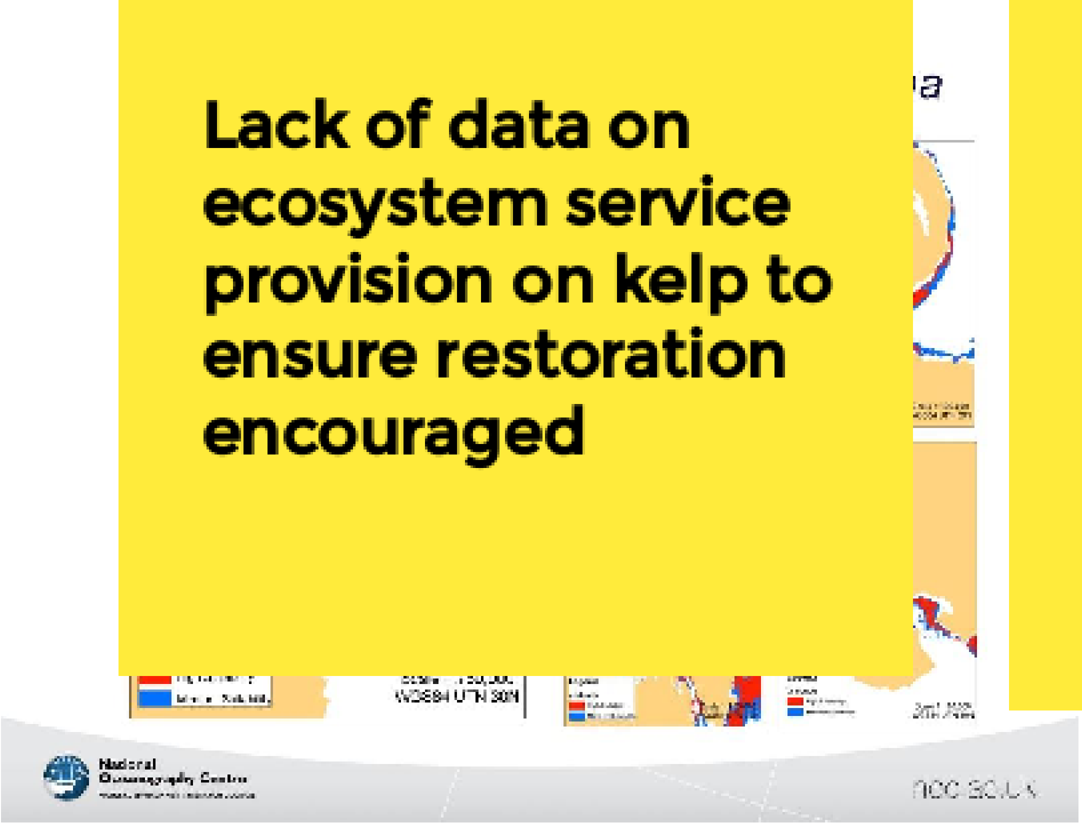
What pressures need to be … s ty … l?

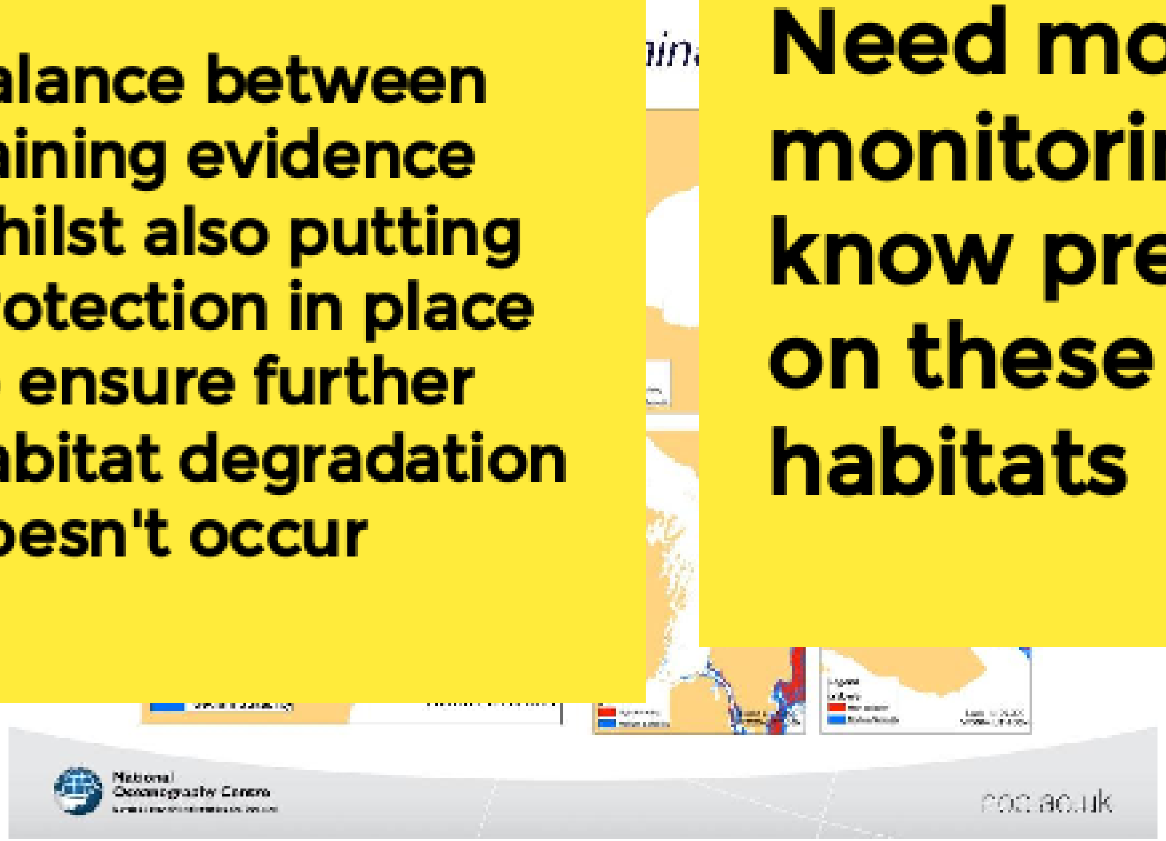
Benefits of having so many different partnerships

What do we do to get this in the public eye and engage

Key, very obvious barrier - very much out of site, out of mind

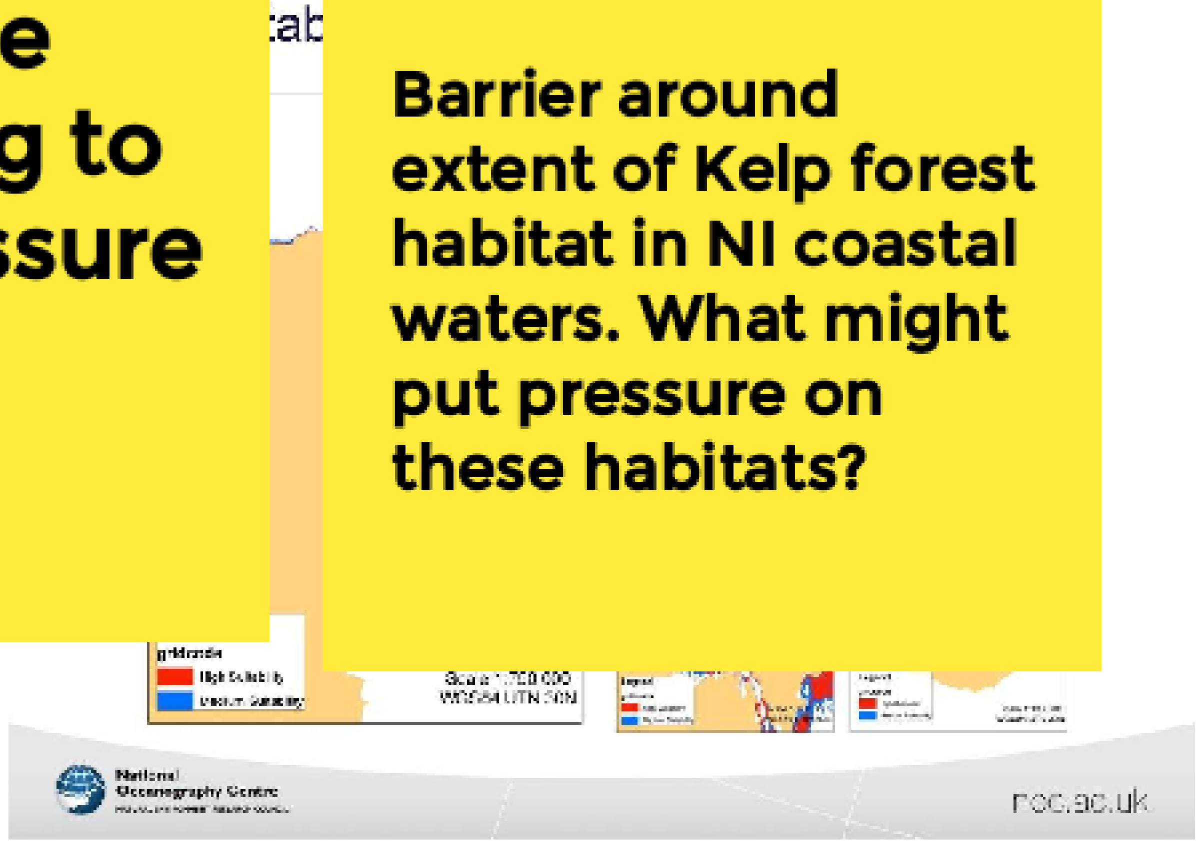


Lack of data on ecosystem service provision on kelp to ensure restoration encouraged



Balance between gaining evidence whilst also putting protection in place to ensure further habitat degradation doesn't occur

Need more monitoring to know pressure on these habitats



Barrier around extent of Kelp forest habitat in NI coastal waters. What might put pressure on these habitats?

Kelp Restoration

What ... oration look like in NI?
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What ... lim ... s type

Kelp situation is slightly unknown in NI - blue carbon focus is elsewhere

Diver records are important

Potential for modiolus and kelp habitats togthetr

Concern about pot fishing in restoration areas

Important to look at circular economy uses for kelp that comes onshore

Concerns about existing baseline data to determine if there has been evidence of loss

Important for local authorities to be involved

Kelp harvesting could be a concern

Kelp Restoration

identify the specific fisherman that would be effected (related to specific fishing practices)

how much bottom contact fishing happens within the NI 4km boundary? How much pressure does this represent

tracking fishing vessels to ID what activities bylaws may effect

demonstrate/explain to stakeholders why mechanical damage e.g. fishing is detrimental for kelp forests

HOW you will restore, mechanism of restoration/transplantation

Look at MPAs which may have mobile gear pans and identify if they are suitable for restoration activities

workpackages for monitoring and research

Sector carbon reduction plan relevance

sussex example really focused on ESs . it's important to identify and 'sell' the benefits to the right people.

DAERA - politician and fishery engagement

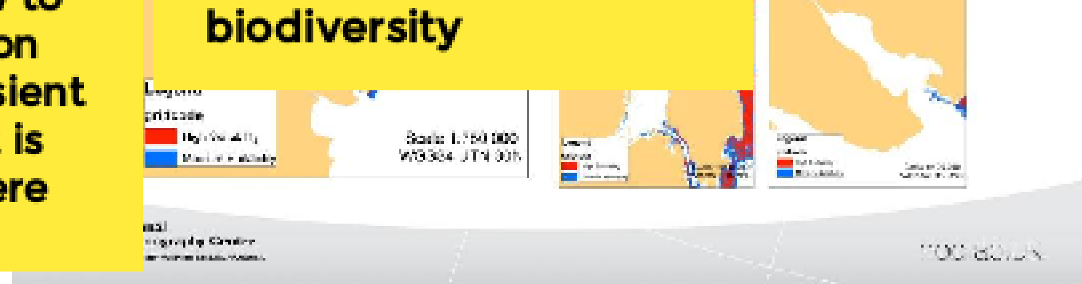
Conservation/restoration aspect in legislative remit?

Turquoise (kelp) carbon – how is it retained, where does it go, how to monitor? Carbon storage is transient (seasonal?) but is stored elsewhere

Identifying stakeholders for engagement - resource and funding source

Identifying collaborators, recreational users? Birders? Divers? Academic, NGO etc. etc.

Monitoring plans for different ESs identified. How are you going to monitor nursey habitat, how are you going to measure development, how are you going to measure biodiversity



Identifying what is a measure of success

Baseline identification to then be able to measure/predict success

Are you going to use academic partners? Is there going to be citizen science involvement

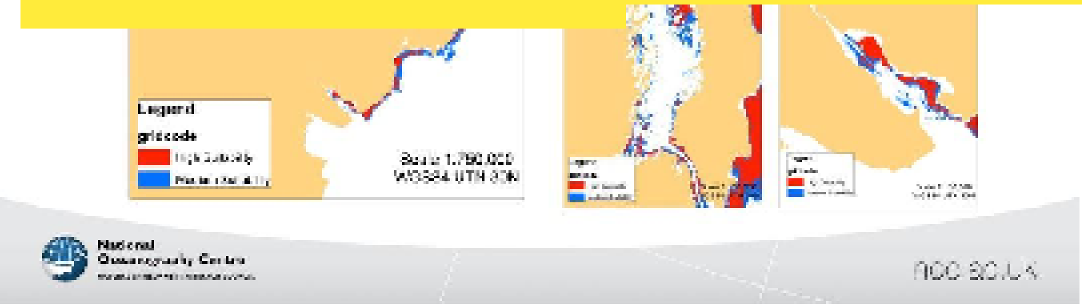
identifying areas where pressures can be removed to allow neration

Work to isolate specific pressures to look at a mitigation plan . e.g create bylaws for specific pressures

Baseline data of where it was before and isn't now rather than just suitablity

Are you just removing pressures or are you planning to try and restore habitats?

What is the potential to restore Kelp



Kelp Restoration

What would this type of restoration look like in NI?

rriers to this type of restoration in NI?

e of restoration in NI?

JNCC habitat suitability and bioenergy souce - dies back in winter so not. A PERMANENT SINK

POsitive from the talk Evidence base from Seasearch divers really important habitat generally & protection for certain species

Licence kelp with environmental benefits - energy food aquaculture beauty health - natural system - Isle of Man had Kelp Cereal 20 years ago

BIM are pushing as up and coming and improving seaweed aquacultures and meeting market demands - grants & Money

Die back in the winter would it be captured in seabed ? Massivly producive what happens to standing crop ?

Important for the multi benefits not just about ticking policy boxes - net benefiti greater then the parts

IPCC looking at long term storage of carbon

Tourism draw

Navigation shipping and fouling as a potential conflict

Dakota - Kelp increasing harvesting for food and energy opportunity and challenge for restortation economic opportunity

Kelp Restoratio

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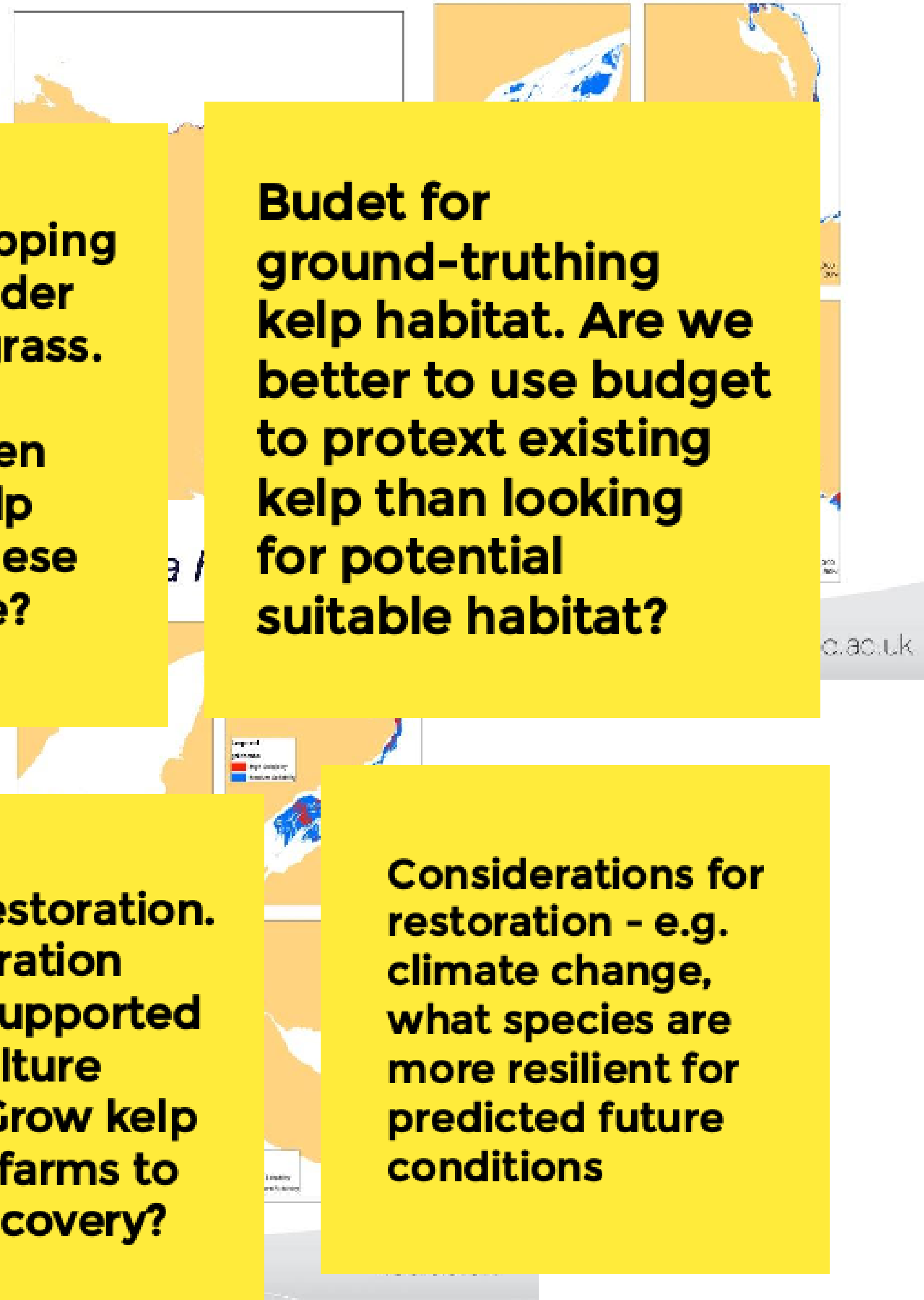
What are the opportunitie ... ora
What pressures need to b ... this

Suitable Habitat for *Laminaria digitata*



Restoration for kelp? Differences between active restoration vs protect and recover e.g. fishing byelaw. Is the second the (only) opportunity for kelp?

to think about habitats as part of the solution - lots of users of the lough (aquaculture) may support initiatives for improved water quality. Dredged areas for ferries will never be a good site for habitat restoration -

feasibility for mapping kelp habitat - harder than for e.g. seagrass. Best practice? Language between kelp-park and kelp forest - should these be rolled into one?

Budet for ground-truthing kelp habitat. Are we better to use budget to protext existing kelp than looking for potential suitable habitat?

Surprise around high suitability for Saccharina in Strangford Lough - more muudy sand. Model substrate parameters used?

Costs of restoration. Kelp restoration could be supported by aquaculture industry. Grow kelp alongside farms to support recovery?

Considerations for restoration - e.g. climate change, what species are more resilient for predicted future conditions

Salt Marsh Restoration

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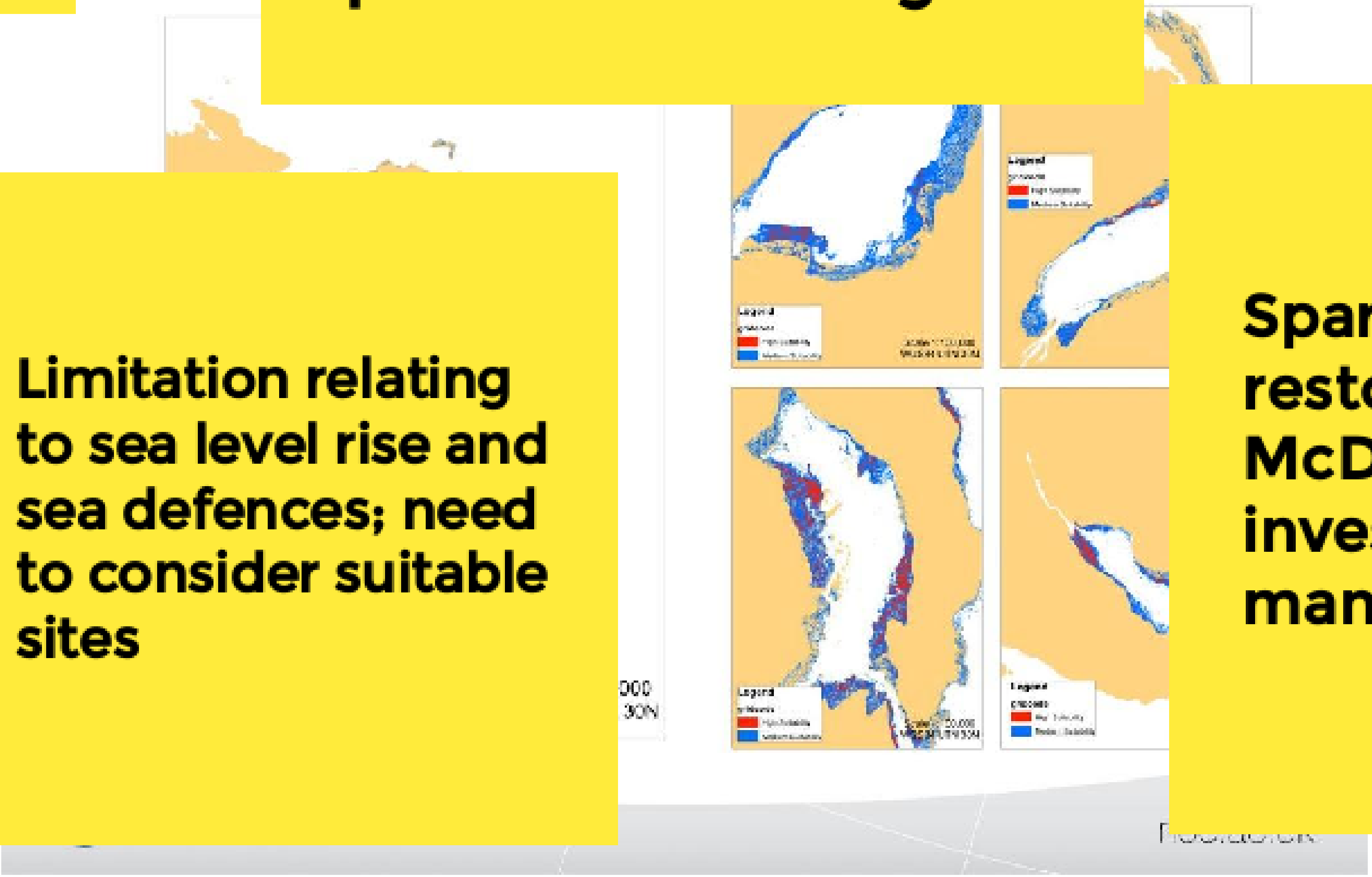
What are the opp… of res…
What pressures r… chieve…

Maps missing suitable habitat layers where saltmarsh occurs currently e.g. Dundrum Bay (Georgia McDowell)

Opportunities in Strangford Lough and Lough Foyle esp. Ballykelly Longfield to Magilligan point where there are no current restrictions (Colin Armstrong) and poss. Belfast Lough?

Currently surveyed by DAERA Intertidal Ecology Team, up to know have focused on Strangford Lough; this year 2021 using UAV to map seagrass extend alongside saltmarsh (where the two overlap) Georgia McDowell



How do we scale up current mapping? What is required for effective saltmarsh monitoring and mapping? Is there an option to tap into Citizen Science? E.g. using kayakers to photograph or map boundary of saltmarsh (Sally S-M)

Limitation relating to sea level rise and sea defences; need to consider suitable sites

Spartina may limit restoration (Georgia McDowell); need to investigate management

Salt Marsh Restoration

...estoration look like in NI?
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...e limited to achieve this type of restoration in NI?

Draft Marine PLna & Marine Policy Statement - should not be in areas which are undeveloped - lack of awareness of coastal squeeze and planning and decisions made by councils

http://www.mccip.org.uk/media/1819/mccip-saltmarsh.pdf

- Creating new saltmarsh don't want to punch through the embankments needs good community negotiations..

Hans - Coastal Squeeze - needs to be able to travel inland - CLimate Change predictions important - need to buy land next to coast for the future - No shore line management plans

Issue of overwheling public interest - eg important infra structure need alternatives to hard engineering - educate people who are making the decisions

OUtreach vital planners don't know about the coast - there is often confusion when water comes back in - education of all

Lack of knowledge Scotland saltmarsh survey minimal mappable unit 3 HA and above Small areas more vulnerable

Opportunity bird life - for tourism eg Larne Lough Storm defences for adaptation and resilience and water quality

Current mapping project and opportunity to map the scattered seagrass - capture carbon but also terrestrial opportunity sinks for marine and terrestrial sources

Sea level predictions using latest data UK and ROI CP18 etc needed and need to be understood - fill in gaps for better predictions

Future sealevel rise IOM no big areas of Salt march but lots of small areas mapping difficult because clumpy

noc.ac.uk

Salt Marsh Restoration

pressures: coastal, sea level rise, coastal squeeze, grazing damage, stocking denisty for balance of restoration and grazing,

Sea level rise to be included in future models?

identifying sensitivity to pollution, runoff, eutrophication.

agri-environment schemes for grazing to levy funding

Need for buffer zones to protect saltmarshes from runoff?

issue of opportunistic green algae which may mask the saltmarsh. Waste water treatment policy engagement

Predictors related to water characteristics are usually not recorded above sea level. This is causing troubles when modelling Saltmarshes and involves a bit more processing (extrapolation) to include in the maps.

identify requirements for initiations e.g. sediment types etc.

Conflicts with other habitats/ecological interests e.g. creaks for birds

Dalgen bay discussion - a place to initiate saltmarsh type habitat? What would be the barriers for initiation rather than supplimentation

Identifying other ESs - protection, food, carbon

Accessibility – identifying 'easy win sites'Should you first do easy sites or invest more in sites that may take more time but have a more effective outcome

Identifying sources of sediment to input into the saltmarsh e.g. dredging (circular 'economy')

Interaction with agriculture

new saltmarsh opportunities rather than supplementing existing saltmarsh. what policy and physical barriers exist to this?

Engagement and identification of specific stakeholders e.g. birders, farmers (shell island saltmarsh lamb is a specific product – a desirable product which can be produced on a restored marsh)

Landownership may need to be addressed site by site case by case. Rather than a larger network approach because of different stakeholders

landowners - much of it is national trust related

assessing the state of them - do habitats need restoring, do pressures need removing,

who is responsible for management currently?

WWT land ownership/RSPB - partnership opportunities with different land owners. where does this ownership overlap with model?

Habita

Salt Marsh Restoration

What would this type of restoration look
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What are the opportunities for this type c
What pressures need to be limited to ac s

How to balance restoration, understand the environment for restoration success

One big storm event can have a large impact

Does NI have large enough areas to restore?

Conflicts with agriculture - how to get farmers to agree to give up land

Barriers with landowners

Visual impact = better for public engagement

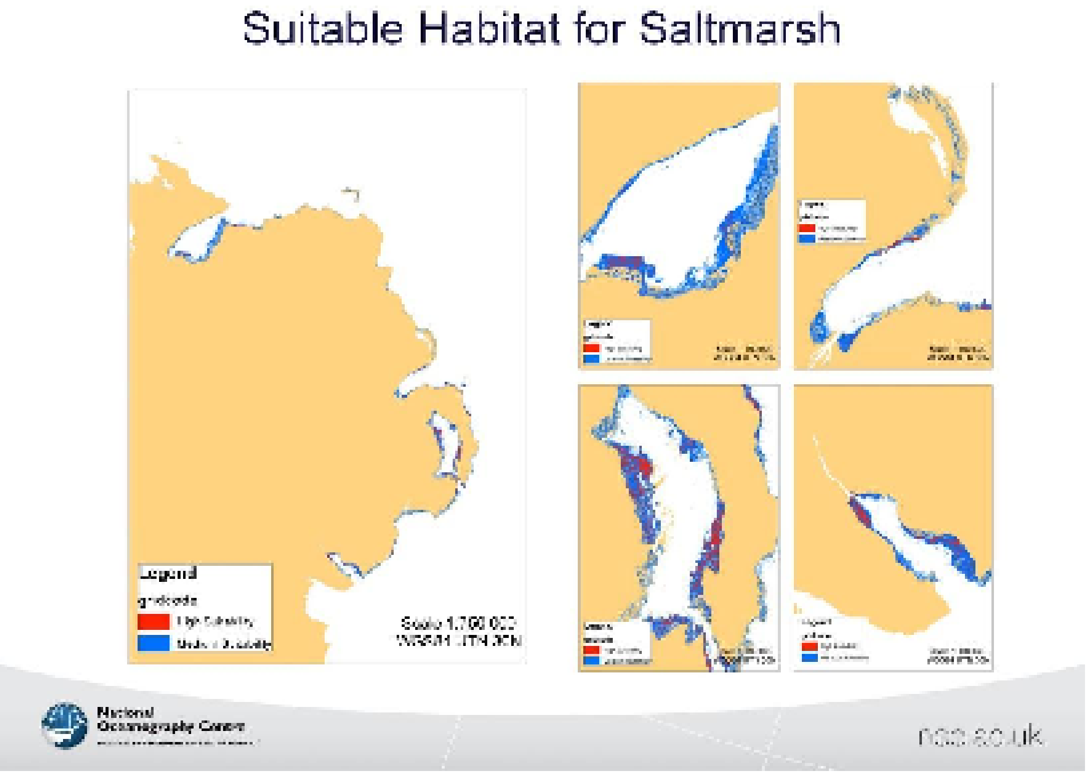
Restoring backwards - claimed agricultural land

Opportunities for managed retreat

Saltmarsh buffering ecosystem service

"Instant" results

Climate change impacts on restoration - we need to understand these before we make management decisions



Salt Marsh Restoration

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Saltmarsh restoration or creation seen as a loss of land that could otherwise be used for agriculture. Engage the public to see variety of benefits- Ecological, economical.

Only small pockets so question of were do we focus on?

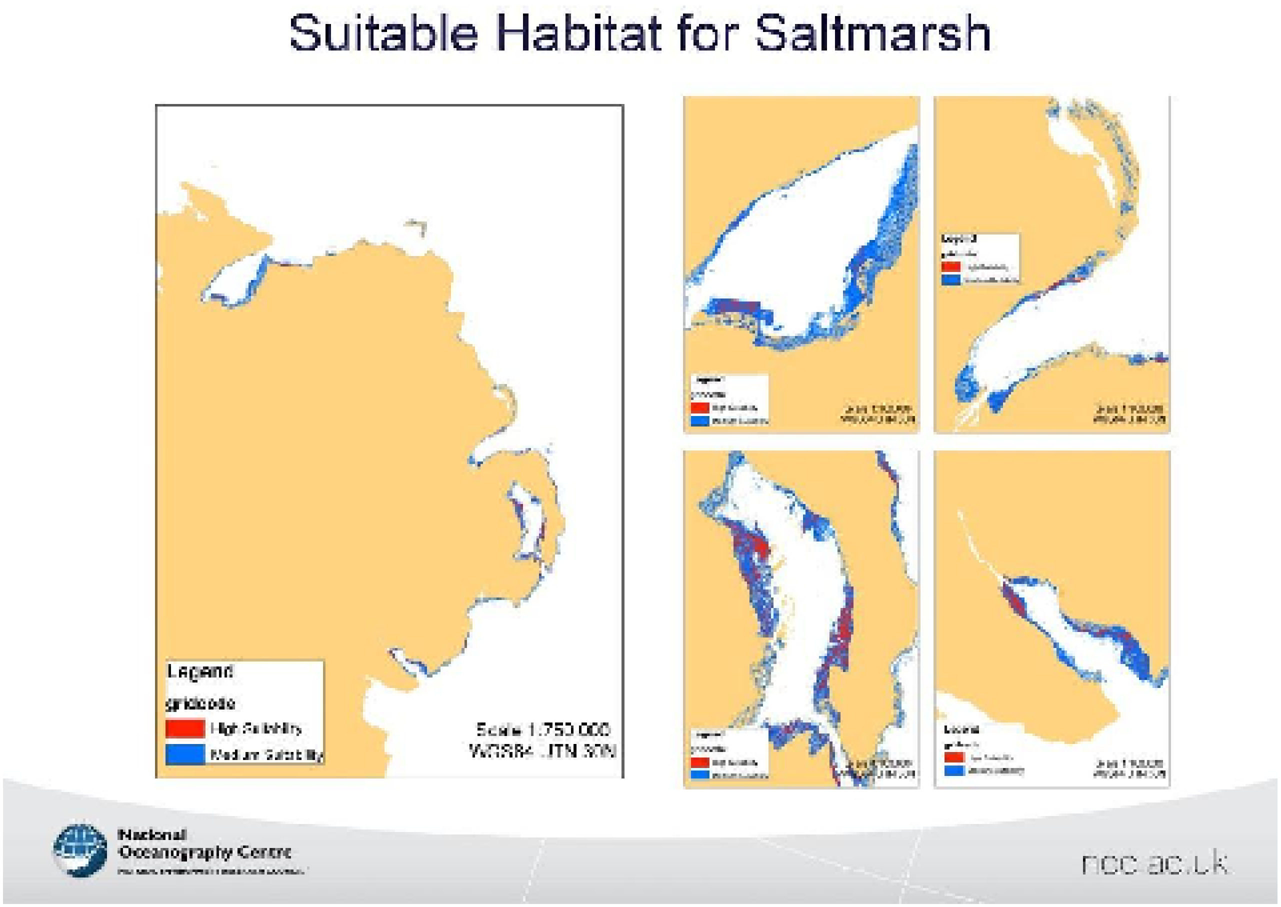
Focus on back end of salt marsh, area impacted by coastal squeeze

Pressures- Land reclamation for agriculture

Idea of shifting baselines, historically how far back do we restore?

Barrier- Inva

Navigating land ownership, economic benefits differ from direct income from agriculture



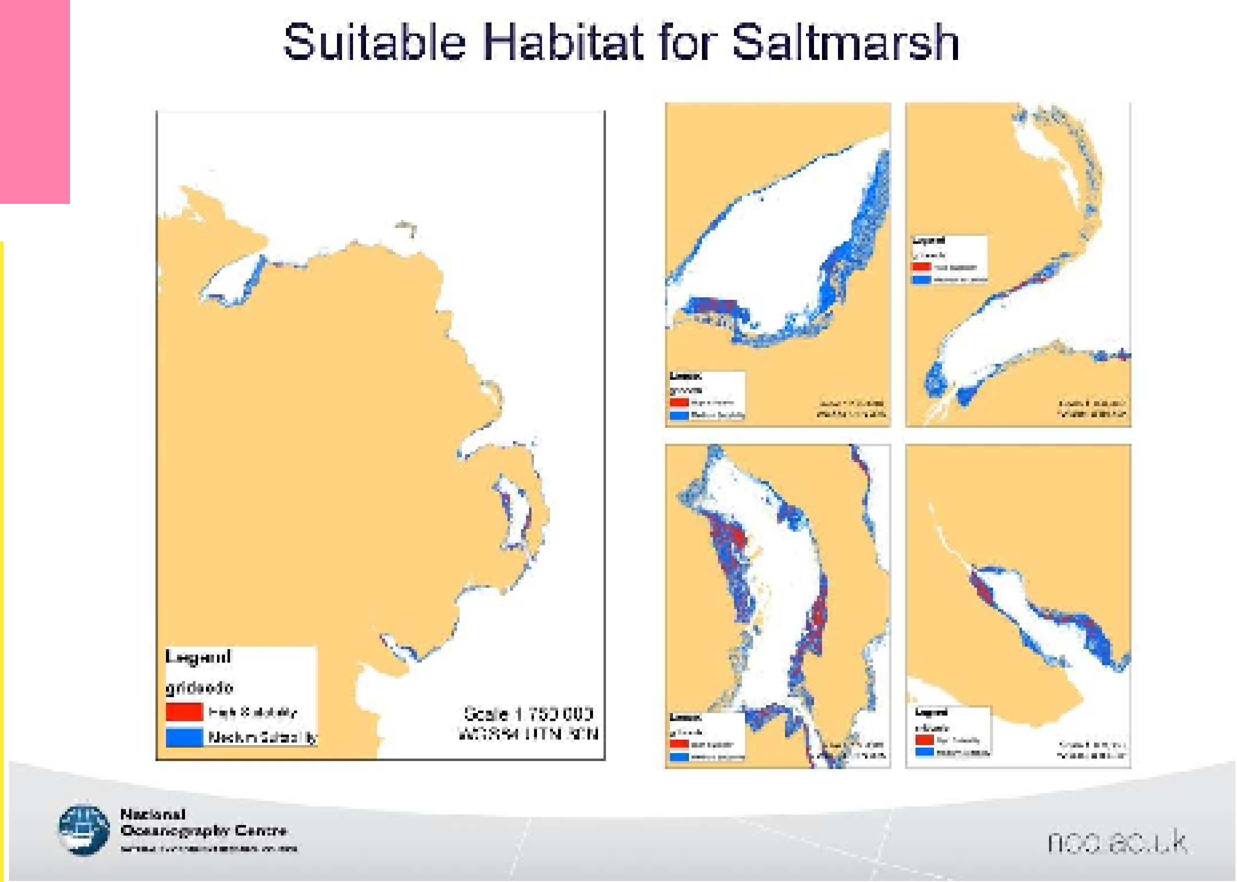
Salt Marsh Restoration

Landowners use saltmarshes for grazing (cattle), rabbits grazing too?

Lough Foyle - water quality classification near saltmarshes = was good in the past (2-3 years ago), not sure what it is like now. Massive explosion of aquaculture there

Opportunity: Current work - working on monitoring and establishing baseline. More interest = drive for legislation = higher priority = more funding?

Pressures: Threats - sea level rising



Sheep waste issue if sheep grazing - controversy between usage for sheep vs shellfish (water quality)

IF funding available = opportunities for landowners and local stakeholders. IF no funding = barrier

Barrier - right technology (e.g. hovercraft), difficult access

Barrier - Baseline on species diversity? Mapping happened in 2020, more to happen this year (North Strangford mapped already).

Barrier: DAERA approaching can cause trust issues with landowners. Actively working with local stakeholders to mitigate this

Barrier: can disturb birds (e.g. skylark) that nest in saltmarshes while mapping.

Opportunity - chatting with landowners and building trust.

Barrier - airport access is difficult. H&S issues (mud - lethal)

Barriers: landowners - little authority on private areas. access (hovercraft can access more areas, but habitat assessment reviews need to be put in place first)

Salt Marsh Restoration

What would this type of restoration look like in NI?
What are the barriers to this type of restoration in NI?
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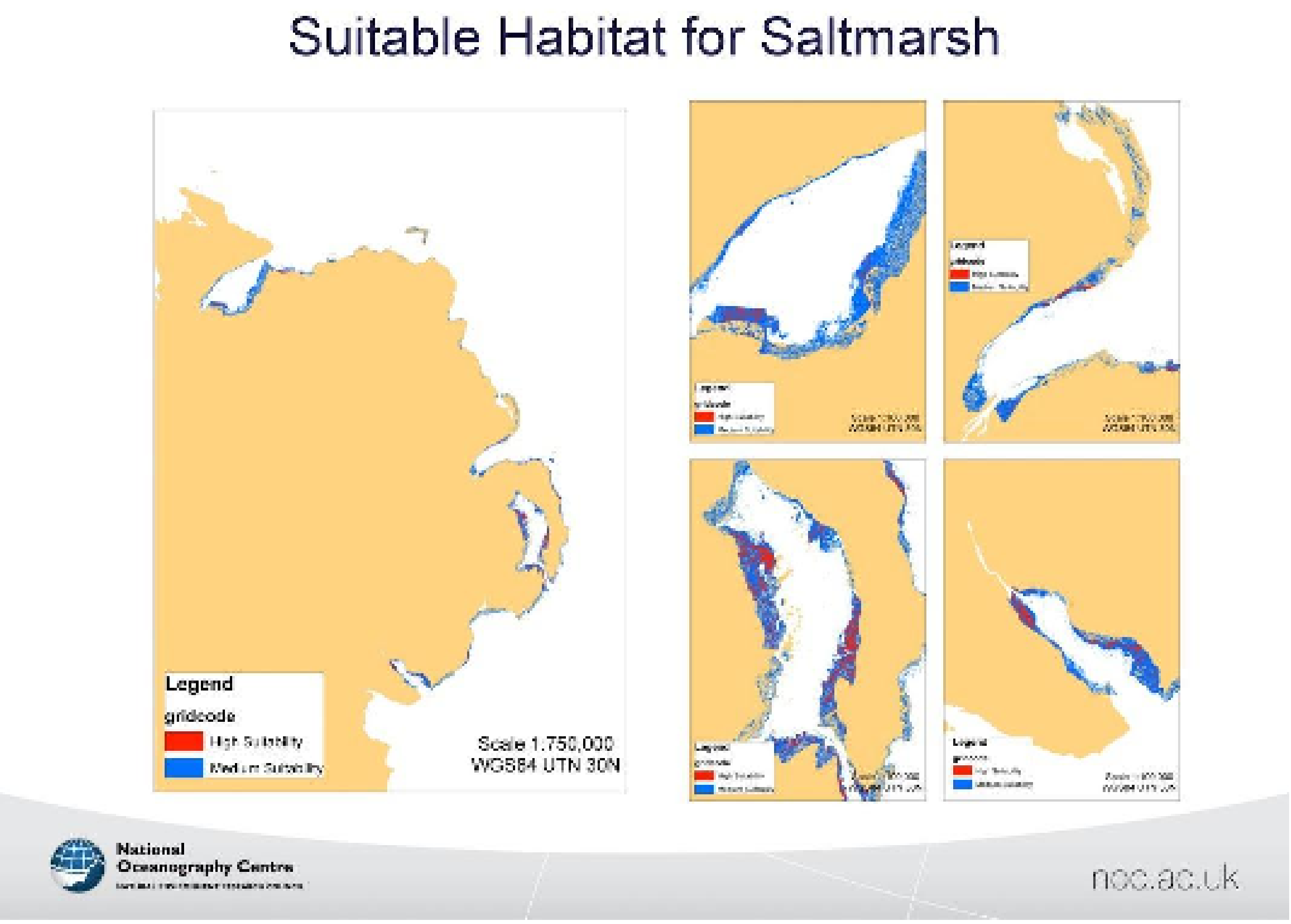
Are there any Managed realignment in NI? What is the condition of NI Salt Marsh - is it degraded or eroded?

Hard locally adjusted figures are needed, coupled with sea defence renewal costs, to determine where and when managed realignment to saltmarsh should be selected.

Is there an issue with Spartina impacting adjacent seagrass beds?



Managed Realignment seems the most valuable coastal blue carbon initiative in terms of quick impact. But comes at high cost due to land prices, coastal access etc.

Challenges of saltmarsh mapping - extent, quality, impacts.

Do we consider Spartina to be an invasive still or is a Naturalised non native? Should it still be used for fringing marsh projects?

Salt Marsh Restoration

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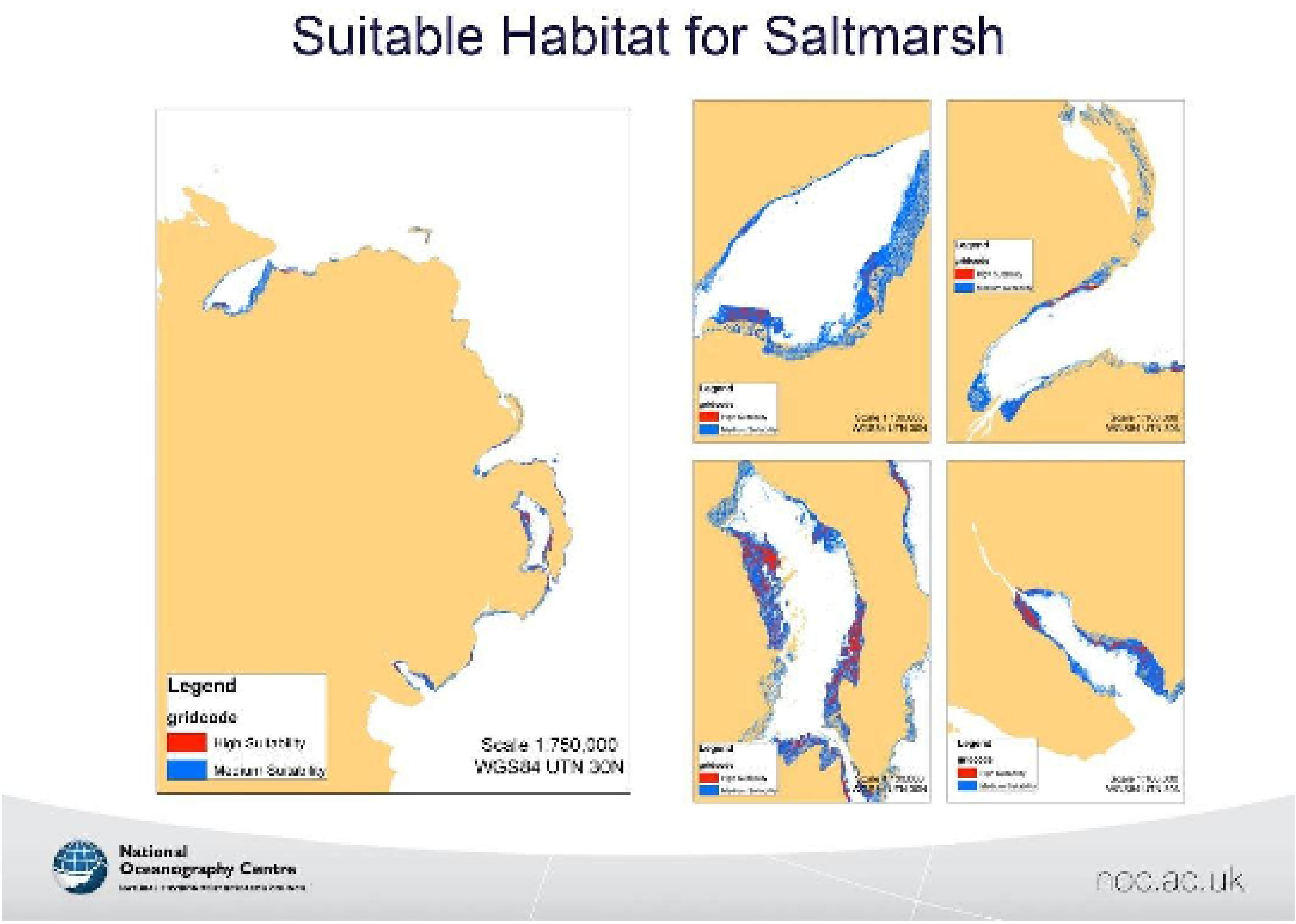

opportunity to engage with land owners and local councils and incorporate into management plans

Need to ensure there is no impact into other important habitats and the ecosystem balance is mantained

Coastal squeeze

Invasives species - Spartina

presures from local faming and unlicensed infrastructure

Sea level rise challenge

Seagrass Restoration

What would this type of restoration look like in NI?
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What pressures need to be limited to achieve this type of restoration in NI?

barrier - covid / man power / equipment / good infrastructure/ dive teams costly / need suitable qualified people to survey and restore

barrier - funding big issues, no money!

genetic analysis and considerations

pressure - nitrates / agric run off / shellfish industry /

In the future there is potential to consider intertidal beds in Mulough

Lack of historical baseline data for restoration

opportunity - seagrass opportunity for blue carbon

barrier - lots of support from public and stakeholders, but hard to achieve in reality, mechanism to do so challenging. Barriers in gov

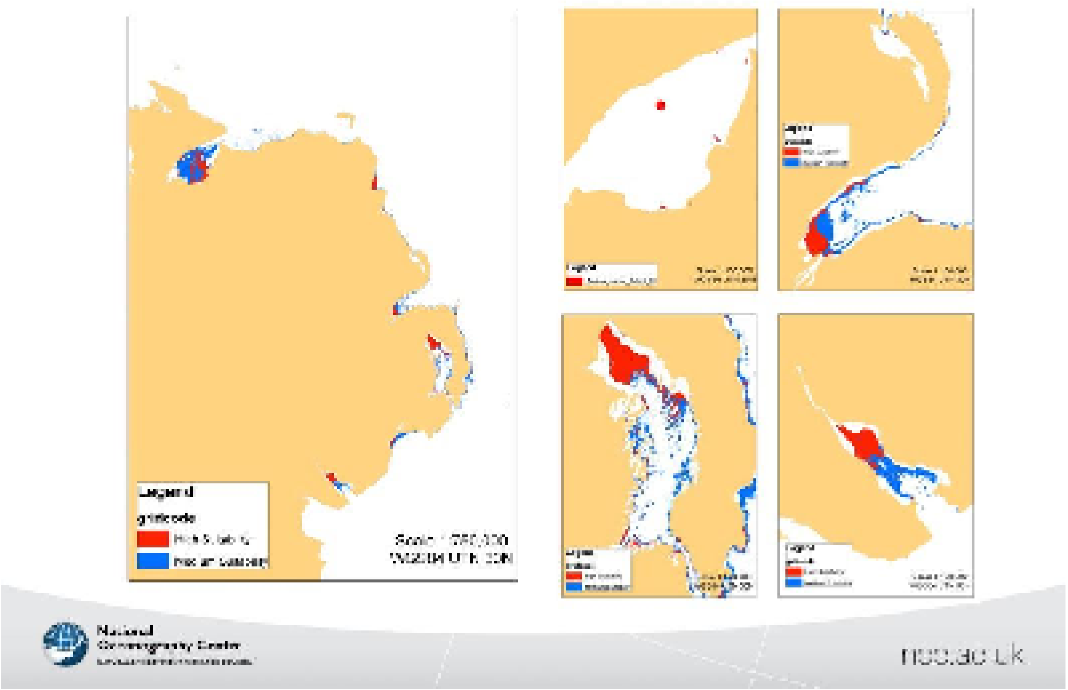
opportunities -education for all user groups

infrastructure cost/funding

barrier - multiple use groups, including commercial and pleasure

barrier - international boundaries,

Suitable Habitat for *Zostera marina*



Seagrass Restoration

What would this type of restoration look like in NI?
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What pressures need to be limited to achieve this type of restoration in NI?

Lots of point data (ie where it is) but not how size and shape of patches. Remote sensing

Barriers and opportunities - Communities! Lots of interest in desire to restore but legistlation not in place. Social and political chanllenges are biggest

Dont know much about genetics. Need to learn more. Collect Zostera for Richard! Funding for genetics available

Do you test sediment quality (sediment chemistry, pesticides etc.)? Probably need to. Might make seagrass unviable. Look at where seagrass is currently present. Certain genotypes might be able to tolerate more difficult conditions

Is it best to put expand exisiting site when restoring or putting a new site? Do it where the conditions are suitable. Legislation (at least in Scot) adjacent site = pop enhancement easier than restoration

No right way - need some best practice guidelines

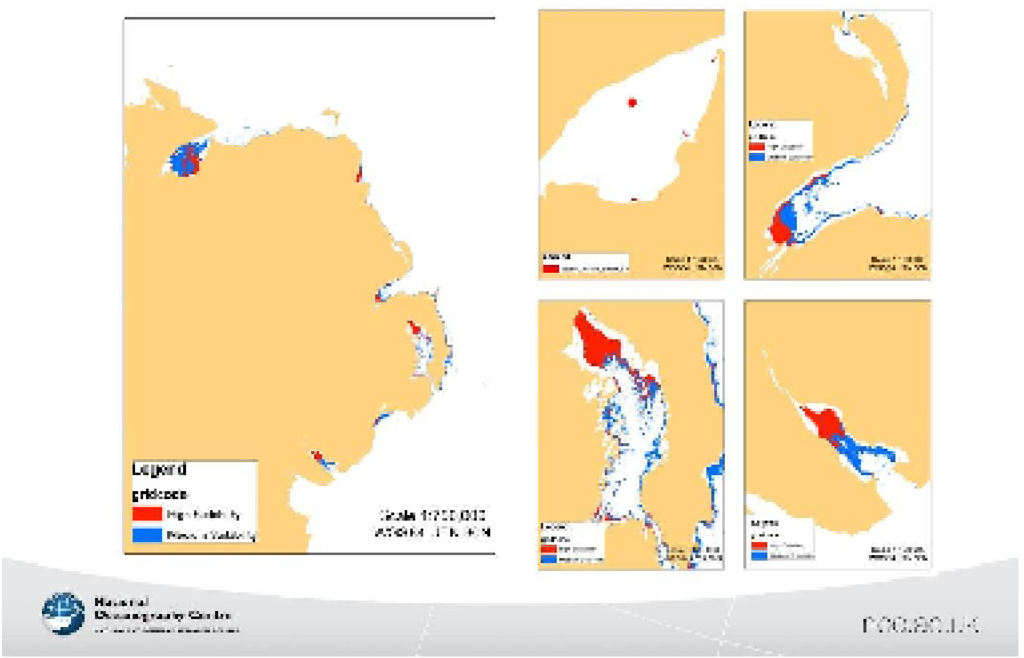
Management of current impacts - reduction in dredging etc. Reduce damaging practices first. But communities might object = communities not on board

should we colocate with other habitats? Yes seascape restoration - co-benefits for biodiversity

Big opportunity for for a blue carbon code. Would need to include some habitat specificity as they sequester at different rates. Lots of interest (fed up with planting trees)

Do we need a seagrass nursery for more projects?

Suitable Habitat for *Zostera marina*



Seagrass Restoration

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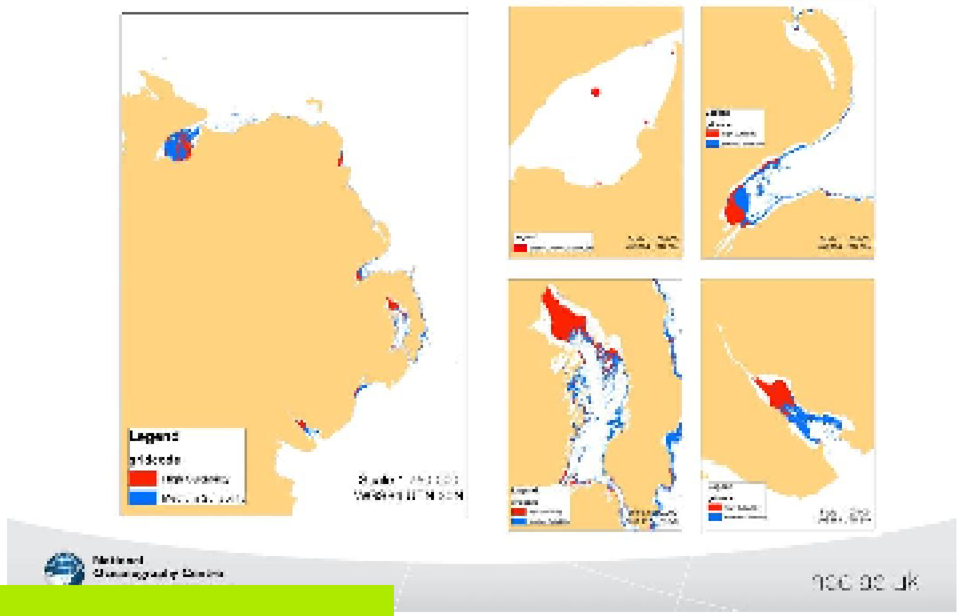
Suitable Habitat for *Zostera marina*



Barrier - boundary issues (Lough Foyle)

Need legislation to address hierarchy of Blue Carbon habitats against species (especially shellfish industry).

Opportunity - government subsidies to shellfish industry, to grow shellfish in a more environmentally - friendly way

Seagrass habitats lost for a reason in most areas (industry, pollution)

Opportunity - recent move towards Climate Change legislation

Need - to define value of blue carbon, ecosystem services and embed into legislation

Pressures - agricultural run-off, pollution, shellfish industry

Opportunity - education!

Restraint - expertise, monitoring every 2 months (need infrastructure in place)

Barriers: funding, storms, negative responses from local government

Seagrass Restoration

What would this type of restoration look like in NI?
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What pressures need to be limited to achieve this type of restoration in NI?

Success should look at biodiversity indicators, resilience and wider ecosystem services rather than blue carbon

Using oysters to clean water near seagrass restoration (i.e. restore native oysters and seagrass together)

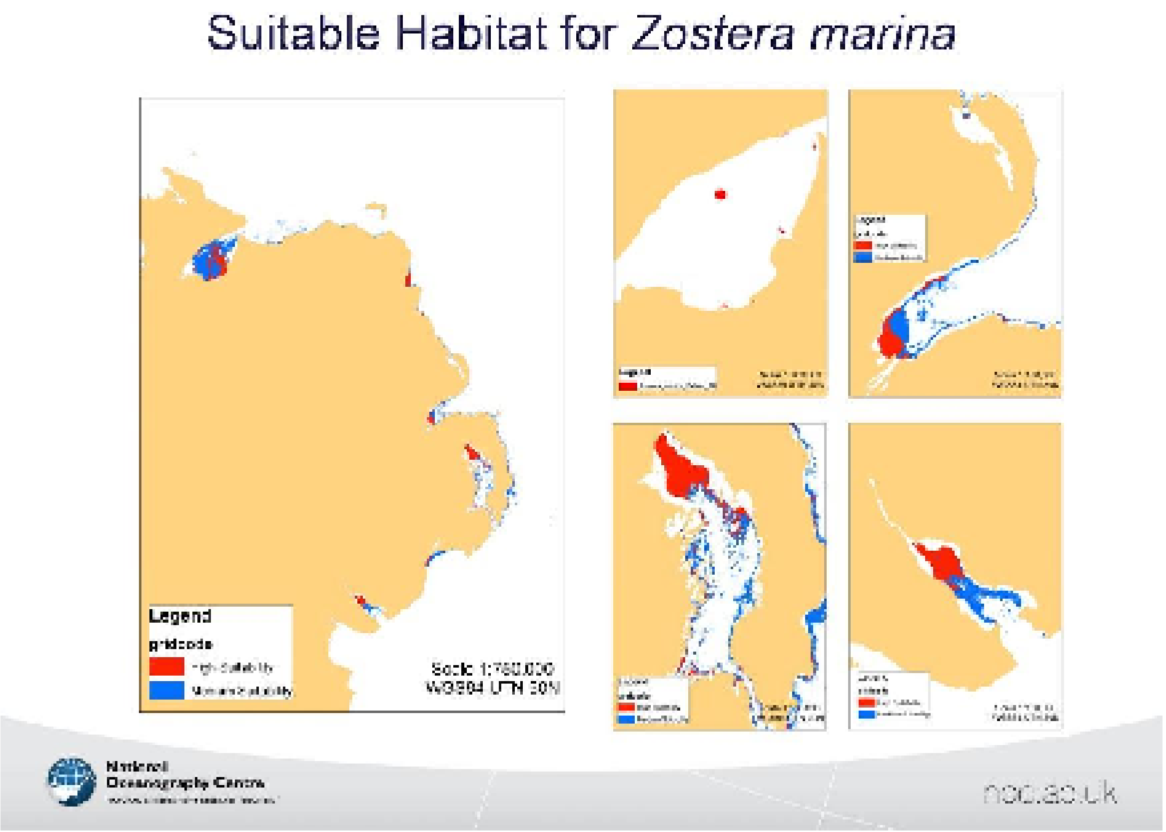
Determine condition of existing habitats to help prioritise areas of restoration and connectivity

Like to see 4 hectares or more in extent. Larger = more resilient.

Connectivity benefits (e.g. Dutch experience)

Community support essential. With stakeholders such as fishermen highlight long term benefits compared to short term gains

Need for joined up restoration with other habitats



Seagrass Restoration

What would this type of restoration look like in NI?
What are the barriers to this type of restoration in NI?
What are the opportunities for this type of restoration in NI?
What pressures need to be limited to achieve this type of restoration in NI?

Matrix of habitats

Fundamental conflict - cost of undertaking preparatory work & licensing is expensive. Restoration is labour intensive. SEA essential

important. Consents take time. Wider strategic approach important - government & other users to get better information on managing the ocean sustainably Countrywide levels. Conflict from user groups & fishermen -

Needs strategic approach for seagrass restoration (SEA). Opportunity maps for the next 10 years

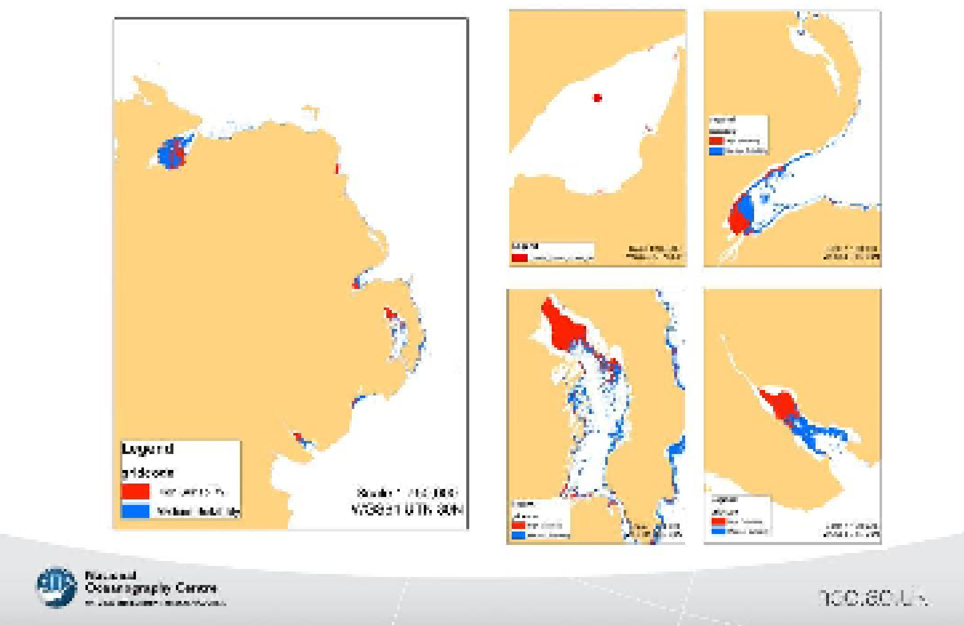
Current pressures in ecosystem and climate projections essential to inform restoration areas

Recreation and by laws on anchoring important

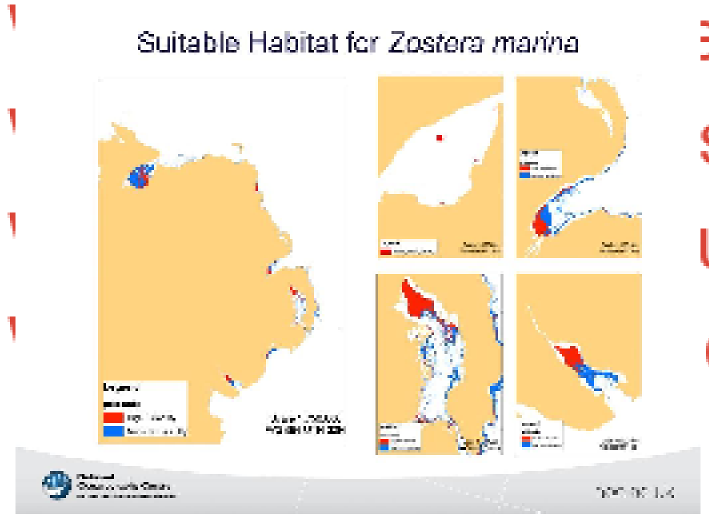
Historical information is important to indicate suitable areas. Ecology will help prioritise areas of restoration

Need to be clear of species of sea grass we are dealing with. Need to be mindful of SPA requirements

Suitable Habitat for *Zostera marina*



Seagrass Restoration



Consider overlap with other habitats - conflicts?

Do the models need refining for more variables, presence and absence, different algorithms to help inform where is suitable. This will change with time as we experience changes in climate

There may be a need for identification of why seagrass hasn't established, have the pressures been removed?

Sealoch focus, what is the water quality in these areas? How much will this impact the success of these types of projects?

Density requirements?

Legislative barriers - NI CC Bill, NI Environment Strategy. Border issues Lough Foyle & Carlingford Lough

Identifying overlap to minimise resource requirement. e.g. co-restoration

Sea loch focus - question 2 Legislative barriers, identifying ownership boundaries and where interests between borders might over lap. E.g. lough foyle

Other users - belfast loch e.g. conflict with aquaculture, possible sources of sediment disturbance which could plume and then settle on seagrass

Seagrass is vulnerable to distrubance, are there measures in place to allow establishment and protect from disturbance?

Stakeholder identification. Engange them in planning and suggestions. Community engangement may be an important source of 'person power'

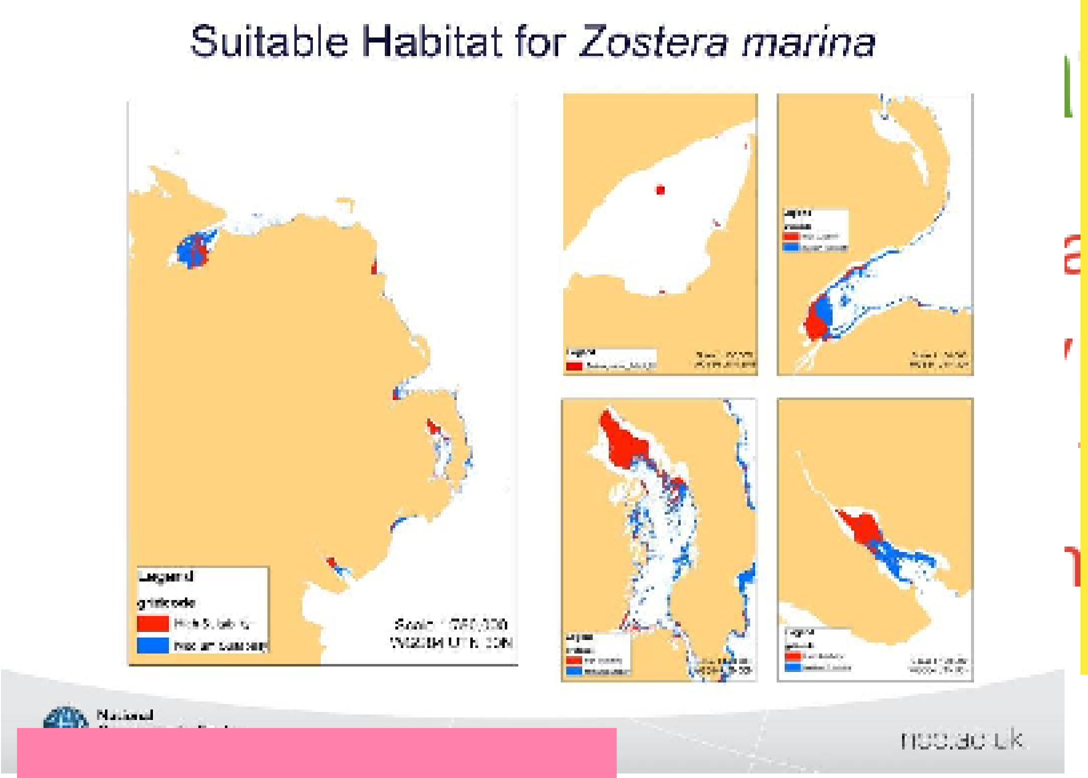
Supplement existing seagrass beds rather than starting from scratch. Would require identification of pressures as to why the existing bed is in a degraded state

Balancing where is most suitable for specific habitats e.g. not restoring saltmarsh where seagrass may be more successful and visa versa

Progress of designation or protection. Resource source? Setting out sites for restoration is not yet planned into managment. Funding resources capacity

Seabed ownership - identifying owners as well as the necessary permits.

Identify limiting factors to colonisation e.g. sediment type, sedimentation, nutrients, light penetration etc.



Look for easy wins first reducing fragmentation - eg Strangford Lough where already protections on paper in plance

Move fundemental pressure through restoration of no take combine restoration together in same areas

Improve existing seagrass habitat - where fragemented increase patch size.

Conflicts with where people are and seagrass restoration

Disease was a problem in Dublin Hans Viser

Where does this fit into 3rd Cycle to WFD plans? DOes Seagrass fit in??

Remove pressures and improving the quality of habitat eg plug gaps to minimise habitat fragmentation

Lough Foyle - substantial native Oyster and dredging happening there some pressures can be part of the management - possiblitly of working hand in hand

Policy hooks to link into practical action help

Pressures: eutrophication/agal smothering. Mooring scars. Dredging. Recreational boating. Disease

Consultation Paper on Climate and Biodiversity Challenges and Opportunities as part of the work that the National Economic and Social Council (NESC) is undertaking on Shared Island in 2021.

Opportunities for a worknig with other land owners eg national Trust who else loughs top and bottom potential for shared projects with ROI

Change type of moorings - seagrass friendly

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Data surrounding existing MPAs to expand MPA boundaries to allow for restoration e.g. Waterfoot MCZ

Collate info on pressures within sites e.g. water quality alongside data and produce a map with layers. Existing sites currently designated for other features not necessarily Blue Carbon habitat

Historical record assessment

Was Zostera noltii data included alongside Zostera marina? The two species overlap so should be

Recommendation: include clarity on data used; and inclusion of polygon map layers

Predictive modelling to expand areas based on existing data