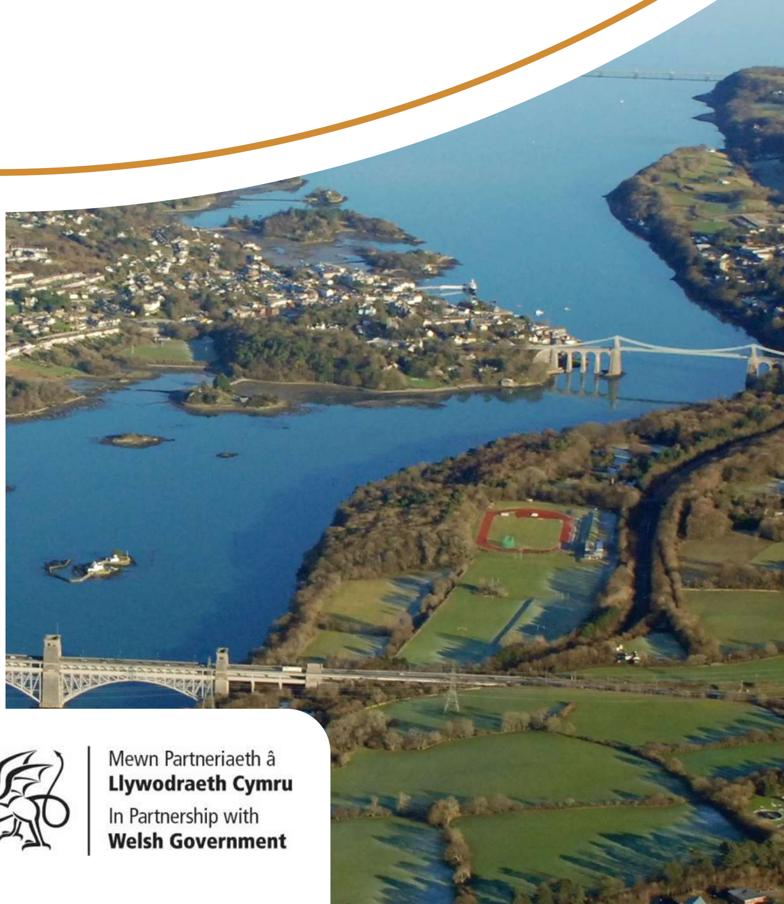
PRIFYSGOL BANGOR UNIVERSITY

Zoological Society of London

A review of marine habitats to inform habitat suitability modelling for the Connecting Conwy Project. 2024-2026



Cronfa Treftadaeth Heritage Fund

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In Partnership with Welsh Government

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Contents

Crynodeb Gweithredol

Mae’r DU wedi profi colledion hanesyddol dramatig mewn cynefinoedd morol gan gynnwys riffiau wystrys brodorol, dolydd morwellt, a gwelyau cregyn gleision. Mae prosiect #NNF3 Cysylltu Conwy (2023–2025) yn ymdrech i asesu potensial adferiad ar raddfa morluniau o fewn ac yng nghyffiniau Afon Menai ac Ardal Cadwraeth Arbennig Bae Conwy.

Cam cyntaf y prosiect oedd cwblhau astudiaeth ben desg gyda’r nod o fireinio dealltwriaeth o gynefinoedd morfeydd, morwellt, riffiau wystrys brodorol a chregyn gleision a gwella paramedrau gofodol yr haenau cyfleoedd presennol. Mae ystod o fethodolegau a setiau data a ddefnyddiwyd ar gyfer mapio cynefinoedd addas wedi’u coladu a’u cyflwyno gan nodi cyfyngiadau, i ganfod bylchau allweddol mewn gwybodaeth sy’n ymwneud â maint, dosbarthiad, cyflwr cynefinoedd, ac i ganfod bygythiadau i’r ecosystem. Mae hyn yn cynnwys edrych ar lenyddiaeth, cofnodion hanesyddol, data monitro ecolegol, setiau data gwely’r môr a hydrodynameg, asesiadau o bwysau amgylcheddol a dulliau blaenorol i ganfod addasrwydd cynefinoedd.

Mae’r adolygiad yn defnyddio gwaith dan arweiniad Prifysgol Bangor, Cyfoeth Naturiol Cymru (CNC), Project Seagrass, Seagrass Ocean Rescue, Ymddiriedolaeth Bywyd Gwyllt Gogledd Cymru, Ymddiriedolaeth Afonydd Gogledd Cymru, Rhwydwaith Wystrys Brodorol y DU ac Iwerddon, a physgodfeydd lleol a phartneriaethau a mentrau cymunedol ledled Gogledd Cymru. Mae hefyd yn adeiladu ar ymdrechion adfer blaenorol gan gynnwys #NNF2 *Dod ag Wystrys Gwyllt yn ôl i Fae Conwy,* mentrau morwellt rhanbarthol, a rhaglenni gwyddoniaeth dinasyddion lleol. Ynghyd ag adolygu’r dystiolaeth, mae’r prosiect wedi ymgysylltu â chynrychiolwyr allweddol lleol drwy weithdai rhagarweiniol, cyfarfodydd un i un a thrafodaethau partneriaeth i ddeall blaenoriaethai lleol, cyfleoedd i gydweithredu, a rhwystrau sy’n atal adfer cynefinoedd morol yn well.

Mae modelau addasrwydd cynefinoedd yn ddulliau gwerthfawr i ragweld safleoedd adfer addas; fodd bynnag, mae eu heffeithiolrwydd yn cael ei gyfyngu gan ansawdd y data, argaeledd a chydraniad gofodol. Dylai allbynnau modelau felly gael eu trin fel rhai dangosol a dylid eu dilysu drwy grynhoi data ac arolygon o safleoedd penodol. Mae bylchau sylweddol yn y dystiolaeth yn parhau yn achos y cynefinoedd targed, yn enwedig o ran data amgylcheddol cydraniad uchel, cofnodion o bresenoldeb rhywogaethau a chwmpas cynefinoedd rhynglanw i lywio modelu addasrwydd cynefinoedd yn well. Mae’r adroddiad hwn yn bwriadu cefnogi ymdrechion cenedlaethol i ddatblygu methodoleg mapio afonol ac i lywio’r gwaith arolygu sydd ei angen i roi sylw i’r bylchau mewn gwybodaeth.

Bydd yr allbynnau o’r astudiaeth ben desg hon yn llywio datblygiad modelau addasrwydd cynefinoedd cydraniad uchel ar gyfer *Ostrea edulis* a *Zostera noltii* gan Brifysgol Bangor. Bydd allbynnau’r model yn llywio arolygon sy’n crynhoi data wedi’u targedu i ganfod addasrwydd cynefinoedd, gan helpu gwaith cynllunio wedi'i dargedu i adfer cynefinoedd morol ar raddfa morluniau Gogledd Cymru yn y dyfodol, i wella gwydnwch, cysylltedd, ac iechyd cynefinoedd a chymunedau arfordirol.

Executive Summary

The UK has experienced dramatic historical losses of marine habitats including native oyster reefs, seagrass meadows, saltmarsh habitats, and blue mussel beds. The *#NNF3 Connecting Conwy* project (2023–2025) aims to assess the potential for seascape-scale recovery within and around the Menai Strait and Conwy Bay Special Area of Conservation.

The initial phase of the project was the completion of a desk-based study aiming to refine understanding of the region's saltmarsh, seagrass, native oyster reefs and blue mussel habitats and improve the spatial parameters of existing opportunity layers. A range of methodologies and datasets used for habitat suitability mapping has been collated and presented noting limitations, to identify key knowledge gaps relating to habitat extent, distribution, condition, and identify ecosystem threats. This includes examining literature, historical records, ecological monitoring data, seabed and hydrodynamic datasets, assessments of environmental pressure and previous habitat suitability approaches.

The review draws upon existing work led by Bangor University, Natural Resources Wales (NRW), Project Seagrass, Seagrass Ocean Rescue, North Wales Wildlife Trust, North Wales Rivers Trust, the Native Oyster Network UK & Ireland, and local fisheries, partnerships and community initiatives across North Wales. It also builds on previous restoration efforts, including #NNF2 *Restoring Wild Oysters to Conwy Bay*, regional seagrass initiatives, and local citizen science programmes. Alongside the evidence review, the project has engaged local key representatives through preliminary workshops, one-to-one meetings and partnership discussions to better understand local priorities, opportunities for collaboration, and barriers to marine habitat recovery.

Habitat suitability models are valuable tools for predicting suitable restoration sites however, their effectiveness is limited by data quality, availability, and spatial resolution. Model outputs should therefore be treated as indicative and should be validated through ground-truthing and site-specific surveys. Significant evidence gaps remain for the target habitats, particularly regarding high-resolution environmental data, species occurrence records and intertidal habitat coverage needed to better inform habitat suitability modelling. This report intends to support national efforts to develop standardised mapping methodology and inform the survey work required to address knowledge gaps.

The outputs from this desk study will now inform the development of high-resolution habitat suitability models for *Ostrea edulis* and *Zostera noltii* by Bangor University. The model outputs will inform targeted, habitat suitability ground-truthing surveys, helping to support future collaborative, seascape-scale marine recovery planning in North Wales, to increase the resilience, connectivity, and health of the coastal habitats and communities.

1. Introduction

1.1 Marine habitat loss and challenges for recovery

The UK has experienced historical losses of up to 95% of native oyster reefs, 92% per cent of seagrass meadows, 85% of saltmarsh habitats and reported declines in blue mussel populations (FAO, 2024b; Garbutt *et al.,* 2024; Heard *et al.,* 2026). We are amid a biodiversity and climate crisis and, as stated in the Second State of Natural Resources Report- SoNaRR2020 (NRW, 2020a), 'building the resilience of ecosystems must form the basis of a swift and immediate response'. Coastal marine habitats are some of the most threatened in Europe (Airoldi, Balata & Beck, 2008), with seagrass and native oyster beds deemed as scarce and reports of reduced mussel spatfall in Wales (Stewart and Williams, 2019; Demmer *et al.,* 2022b; Hayden-Hughes *et al.,* 2023). These intertidal habitats covered large areas along the Welsh coast but have unfortunately experienced historical losses in their extent and condition, as reported across the UK and globally. There were productive native oyster beds during the 18th and 19th centuries in the Menai Strait and around Anglesey with recorded landings of 8,000 oysters daily in Pwllheli but presently, only remnant populations remain in South Wales (Hayden-Hughes *et al.,* 2023).

Regionally, Wales has 76 km² of saltmarshes, 6.9 km^2 blue mussel beds, 8.86 km² of seagrass beds, and 0.01 km² of native oyster beds mapped (NRW, 2019; 2020b; Armstrong *et al.,* 2021; NSAP, 2024) Intertidal mudflats, native oysters, blue mussel, horse mussel and seagrass beds are listed on the OSPAR Convention list of 'threatened and/or declining species and habitats' in the North-East Atlantic. These valuable marine habitats are vulnerable to anthropogenic activities from land claim, coastal squeeze, overfishing, pollution affecting water quality and clarity, the introduction of invasive non-native species (INNS) or diseases/pathogens, and threats from climate change rising sea level and increase in extreme weather events. Resilience and survival of marine habitats to these increasing pressures is unknown, however interventions, whether active restoration or relieving pressures, can help species recover. In recent years, *Z. noltii* extent has increased in parts of Wales in response to management of waterways (Bertelli *et al.,* 2018; Moore *et al.,* 2021; Jackson-Bué *et al.,* 2025d; West *et al.,* 2025)

Welsh Government refreshed 'The Nature Recovery Action Plan for Wales' in 2020/21 aiming to 'halt the decline in biodiversity by 2020 and then reverse the decline, for its intrinsic value, and to ensure lasting benefits to society' through legislative frameworks put in place by the Well-being of Future Generations Act 2015 and the Environment (Wales) Act 2016. Future Wales – the National Plan 2040 defines outcomes aiming to achieve 'biodiverse, resilient and connected ecosystems', 'which are decarbonised and climate resilient', and 'places that sustainably manage their natural resources and reduce pollution'.

In 2021, a NRW evidence report was published titled 'Restoring marine and coastal habitats in Wales: identifying spatial opportunities and benefits' showing the potential of marine habitat restoration opportunities in Wales (Armstrong *et al.,* 2021). This report highlights the potential to restore of seagrass, saltmarshes and mudflats, and reef building species including native oysters and provides a valuable basis for this project. An increasing evidence base illustrates the critical value of these marine habitats for carbon storage and other provisioning services such as fishery production, nutrient cycling and coastal defences, upon which Nature based Solutions (NbS) depend to deliver climate mitigation and halt biodiversity loss.

To help meet legislative duties and conservation objectives, better understanding is needed of the habitat extent, distribution and condition of marine habitats identifying the barriers to recovery and facilitating local buy-in to strengthen the health and resilience of the coastal environment.

1.2 From single-species to seascape-scale recovery

The *#NNF2 Restoring Wild Oysters to Conwy Bay project* (2023–2025), delivered in partnership between the Zoological Society of London (ZSL) and Bangor University completed the first small-scale research trial to assess the feasibility of oyster restoration in this area. While the restoration of native oysters provides important ecosystem services — water filtration, biodiversity enhancement, and cultural reconnection — the broader ambition of recovering Conwy Bay's coastal ecosystem cannot be achieved through recovery of a single habitat or species in isolation. To realise the full potential of nature recovery locally, requires a shift from targeted, single-species interventions to coordinated, seascape-scale restoration across the mosaic of habitats that together define this coastline, in line with the principles set out in the Lawton Review (Lawton *et al.,* 2010)— that ecological networks should be "bigger, better, and more joined."

This ambition is grounded in a strengthening body of scientific evidence, that coastal habitats such as oyster reefs, seagrass meadows, saltmarshes, and mudflats are not independent systems — they are tightly bound together by flows of water, nutrients, sediment, and organisms. Preston *et al.,* (2025), synthesised ecological connectivity across temperate coastal seascapes, demonstrating that ecosystem functioning and the full delivery of ecosystem services require a healthy mosaic of connected habitats. This reflects the core message of the Lawton Review, which emphasises that fragmented habitats limit ecological function, while well-connected systems enhance resilience and recovery. Crucially, restored oyster reefs adjacent to saltmarsh and seagrass habitats support higher fish and invertebrate densities than isolated reefs

(Figure 1), and connected habitats are demonstrably more productive, more resilient, and more beneficial to people than the sum of their parts (Preston *et al.,* 2025).

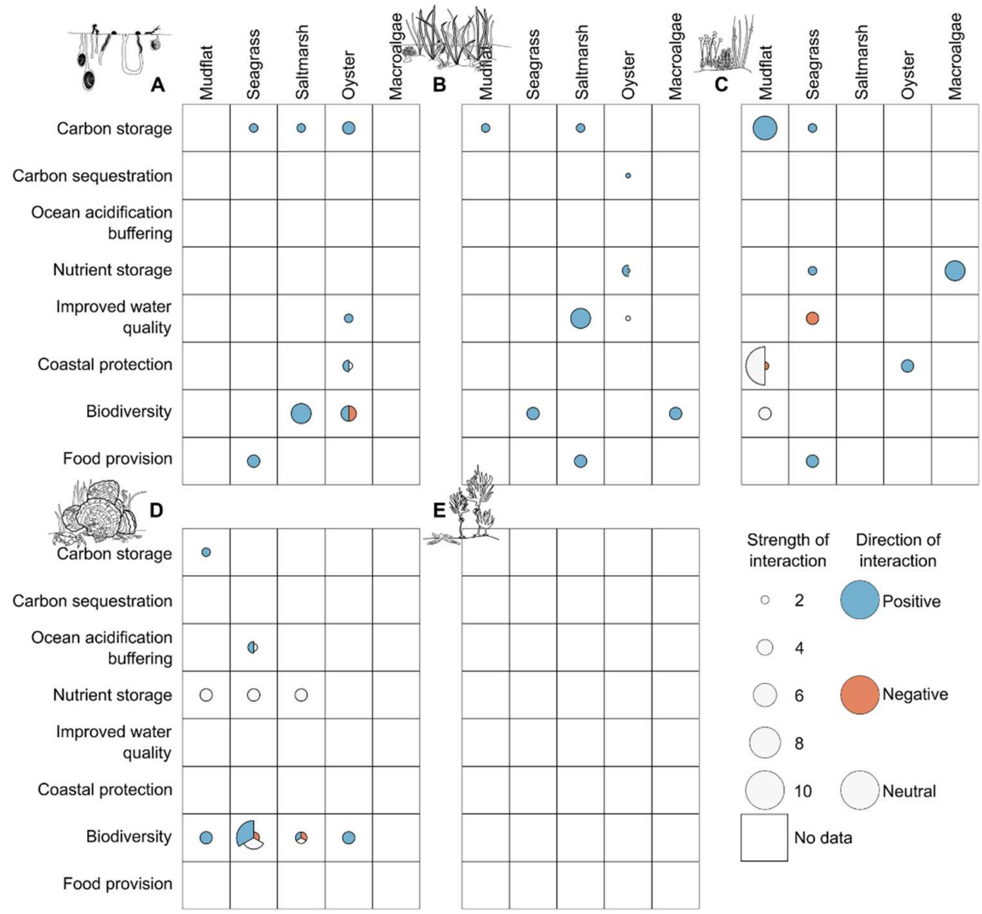

Figure 1. *Matrix of ecological connectivity across coastal temperate habitats and its effect on ecosystem service delivery. (Source: Preston et al., 2025)*

This evidence aligns with international and national policy commitments, including Target 2 of the Kunming-Montreal Global Biodiversity Framework, which calls for 30% of degraded ecosystems to be under effective restoration by 2030, with an explicit focus on enhancing ecological connectivity. In Wales, the Well-being of Future Generations Act 2015, the Environment (Wales) Act 2016, and the Nature Recovery Action Plan provide the legislative framework underpinning this ambition.

The *#NNF3 Connecting Conwy: A plan for seascape scale recovery of coastal habitats in Conwy Bay and the Menai Strait* responds directly to this— building on the foundations of the previous marine habitat recovery work, including native oyster restoration trials and local seagrass restoration efforts, to take a whole-system approach to marine habitat recovery across Conwy Bay and the Menai Strait

1.3 Area of interest

The *#NNF3 Connecting Conwy*, funded through the Nature Networks Fund (round 3) delivered by the Heritage Lottery Fund on behalf of the Welsh Government, aims to conduct the groundwork to drive the long-term recovery, connectivity, and resilience of the heritage through seascape scale recovery of marine habitats in the Conwy Bay and Menai Strait region. Marine habitats provide vital ecosystem services by improving water quality, sediment stabilisation, increasing biodiversity, providing nursery grounds for commercial species and hold cultural value for local communities. By engaging with existing local coastal partnerships, interested parties and communities, this project delivered in partnership between ZSL and Bangor University, aims to identify the key challenges to restoration, and build upon existing work to help develop a collaborative plan for marine habitat recovery locally. Through a holistic approach that integrates habitat restoration, community engagement, and long-term planning, our project seeks to leave a positive legacy for the benefit of both present and future generations.

As one of the largest university centres for marine science in Europe, the School of Ocean Sciences at Bangor University has an international reputation in multi and interdisciplinary research in the areas of earth system science, climate change and marine conservation and resource management. Applied research and community relevant work in the School of Ocean Sciences has used fundamental understanding to guide applied areas of research including conservation, fisheries, aquaculture, marine renewable energy, improved weather forecasting, flood risk assessment and coastal defence.

ZSL is an international conservation science charity working to create a world where wildlife thrives. As a learned society, ZSL has advanced much of humanity's understanding of the natural world for nearly 200 years. Today, ZSL focuses on inspiring collective action and enabling wildlife recovery through science, education, and global fieldwork. Key areas of work include supporting communities to coexist with wildlife by strengthening human-wildlife connections through training, developing and implementing recovery solutions for threatened species to restore ecosystems promoting health and resilience, and providing scientific evidence and tools to inform policy and accelerate conservation efforts globally. ZSL leads the Transforming the Thames Partnership, a Seascape Scale Restoration Project, which brings together industry, government, environmental groups, and landowners with a shared vision of a restored, reconnected, and resilient Thames Estuary. Together, the Partnership is working to protect, repair, and restore the fragmented habitats of the Greater Thames Estuary — one of Europe's most important wildlife sites — including saltmarshes, seagrass meadows, and oyster reefs. The first phase of work aims to restore 320 hectares of coastal habitat by 2030, with longer-term ambitions to create a fully connected and thriving seascape for both wildlife and local communities.

1.4 Aim and objectives

The initial phase of the project involved a review of the existing literature and available data to understand the current extent and condition of key marine habitats and consolidate existing survey work. This provides an evidence base to inform updated habitat suitability mapping work, and to support future seascape-scale restoration planning.

This desk study aims to refine understanding of the region's marine habitats and improve the spatial parameters of existing opportunity layers. A range of methodologies and datasets used for habitat suitability mapping has been collated and presented noting limitations, to identify key knowledge gaps relating to habitat extent, distribution, condition, and identify ecosystem threats. This report intends to support national efforts to develop standardised mapping methodology and inform the survey work required to address knowledge gaps.

The overall aim of the project is to increase the resilience, connectivity, and health of the marine habitats within and surrounding the Menai Strait and Conwy Bay SAC, working in partnership with local interested parties, and through engaging a wider range of people, to conduct the groundwork needed to develop a plan to scale up marine habitat recovery locally.

This report represents the first stage of that process, reviewing existing literature and frameworks to inform habitat suitability assessments as part of *#NNF3 Connecting Conwy: A plan for seascape scale recovery of coastal habitats in Conwy Bay and the Menai Strait*. Habitat suitability models will be developed by Bangor University to predict the suitability of the establishment of key marine habitats: (1) European flat oyster reefs (*Ostrea edulis*) and (2) seagrass meadows (*Zostera noltii*) within and surrounding the Conwy Bay and Menai Strait region.

2. Habitat Suitability Modelling

2.1 Approach and Limitations

Habitat suitability models (HSMs), also referred to as species distribution models, are used to predict the spatial suitability of habitats across a defined spatial landscape, using a set of ecologically relevant environmental variables and known species occurrence data. As such, HSMs are widely applied as an initial tool for assessing site suitability in coastal habitat restoration. Habitat suitability modelling (HSM) has previously been applied to map the distribution and predict site suitability for seagrass beds and native oyster reefs, (Armstrong *et al.,* 2021; Bertelli *et al.,* 2022; Castle *et al.,* 2022; Pogoda *et al.,* 2023; Stechele *et al.,* 2023; Grigg *et al.,* 2025; Pereiro *et al.,* 2025 Smith *et al.*, 2025 etc.). The accuracy of HSMs relies on the quality, resolution, and relevance of the input environmental variables.

HSMs require two types of input data; (1) species presence-absence data (also known as response variables) and (2) environmental datasets (also known as predictor variables). The spatial extent and resolution of the model are constrained by the availability and quality of these datasets. Common modelling approaches include general additive models (GAM) and Maximum Entropy (MaxEnt) models. Reviews such as Bertelli *et al.,* (2022), provide detailed comparisons of modelling approaches for seagrass habitats. HSMs aim to predict the probability of habitat occurrence across a defined spatial landscape and are therefore valuable tools for informing marine spatial planning and restoration decision-making.

Habitat suitability modelling is widely used for interpolating spatial data to predict where environmental conditions are favourable for the establishment of marine habitats including seagrass meadows, oyster reefs, mussel reefs, saltmarshes, kelp forests, mangroves, horse mussel reefs and *Sabellaria* spp. reefs (Martínez *et al.,* 2018; MMO, 2019; Armstrong *et al.,* 2021; Bertelli *et al.,* 2022; Castle *et al.,* 2022; Smeaton *et al.,* 2022; Jaffé *et al.,* 2025; van der Meer *et al.,* 2025 etc.). Restoration handbooks and best-practice guidelines such as Preston *et al.,* (2020), Gamble *et al.,* (2021), Hudson *et al.,* (2021), and Hughes *et al.,* (2023), often recommend the use of HSM outputs (where available) as indicators of potential habitat suitability to support initial site selection. However, the usefulness of these outputs depends on the spatial resolution and accuracy of the underlying data. Model performance is limited by data availability, quality and temporal and spatial resolution, and uncertainty should be explicitly accounted for during model development and interpretation (Robinson *et al.,* 2017).

2.2 Current review

A review of available literature and resources was conducted to inform habitat suitability assessments of the environmental characteristics known to influence the distribution of native oyster reefs, blue mussel beds, seagrass meadows (*Zostera marina* and *Z. noltii*) and saltmarshes. Environmental data availability is a critical factor in determining the feasibility and reliability of HSMs.

This review will synthesise previous marine HSM and survey data for Wales (e.g. Bertelli *et al.,* 2017; 2022; Brazier, 2013; Castle *et al.,* 2022; Dewey *et al.,* 2020; Kay, 1998; Tillin *et al.,* 2020; Armstrong *et al.,* 2021) alongside learnings from broader studies from the UK and other countries. This approach aims to build on existing knowledge, minimise duplication of effort, and identify key data gaps.

All relevant datasets and findings will be used by Bangor University to develop a high-resolution model for *Ostrea edulis* and *Z. noltii* along the North Wales coastline. These HSM outputs aim to support the refinement of existing "opportunity" mapping layers and provide spatially explicit evidence to inform habitat restoration and management. In addition, the modelling process will highlight knowledge gaps and data limitations associated with applying HSMs at local, fine spatial scales.

3. Study area

The *#NNF3 Connecting Conwy Project*, is based in north-west Wales and focuses on supporting future efforts to improving the condition, resilience and connectivity of marine habitats within and surrounding the Menai Strait and Conwy Bay Special Area of Conservation (SAC) (See Figure 2). This area, which covers approximately 265 km^2 and supports Annex I habitats under the EU Habitats Directive for the provision of ecosystem services and processes.

3.1 Designations and Conservation Status

There are two Special Protection Areas (SPAs), seven Special Areas of Conservation (SACs) which lie within the Conwy Local Development Plan (LDP) area, and eight SPAs and eight SACs located or partially located within the Anglesey and Gwynedd Joint LDP area including Menai Strait and Conwy Bay SAC, Liverpool Bay SPA and Traeth Lafan SPA (Conwy Local Development Plan 2007-2022). Both LDPs state the importance to conserve and enhance biodiversity and connectivity. The region also includes the following designations for Sites of Special Scientific Interest (SSSIs): Aber Afon Conwy, Glannau Penmon – Biwmares, Coedydd Afon Menai, Newborough Warren - Ynys Llanddwyn, Y Foryd, Morfa Dinlle SSSIs, protecting the important marine species and habitats such as salt marsh, seagrass meadows. Although native oyster and blue mussel beds are not a protected feature of these sites. These are 'habitats of principal importance for the purpose of maintaining and enhancing biodiversity in relation to Wales' under Section 7 of the Environment (Wales) Act 2016. For example, Traeth Lafan SPA and SSSI contain a range of intertidal habitats such as sheltered mudflats, saltmarsh, natural blue mussel bed, exposed sand banks and one of the few *Zostera noltii* (dwarf eelgrass) beds in Wales. These habitats support large numbers of invertebrates and critical nursery grounds for fish species providing rich feeding grounds for waders and wildfowl including Eurasian curlew and common oystercatcher. These designations are under the Priority Ecological Network and Marine Protected Area (MPA) Network Management Framework for Wales. Appendix 1 sets out a full list of the MPAs within the project area. Our project will focus on improving the resilience of the heritage within the area by planning future action for seascape scale recovery of marine habitats.

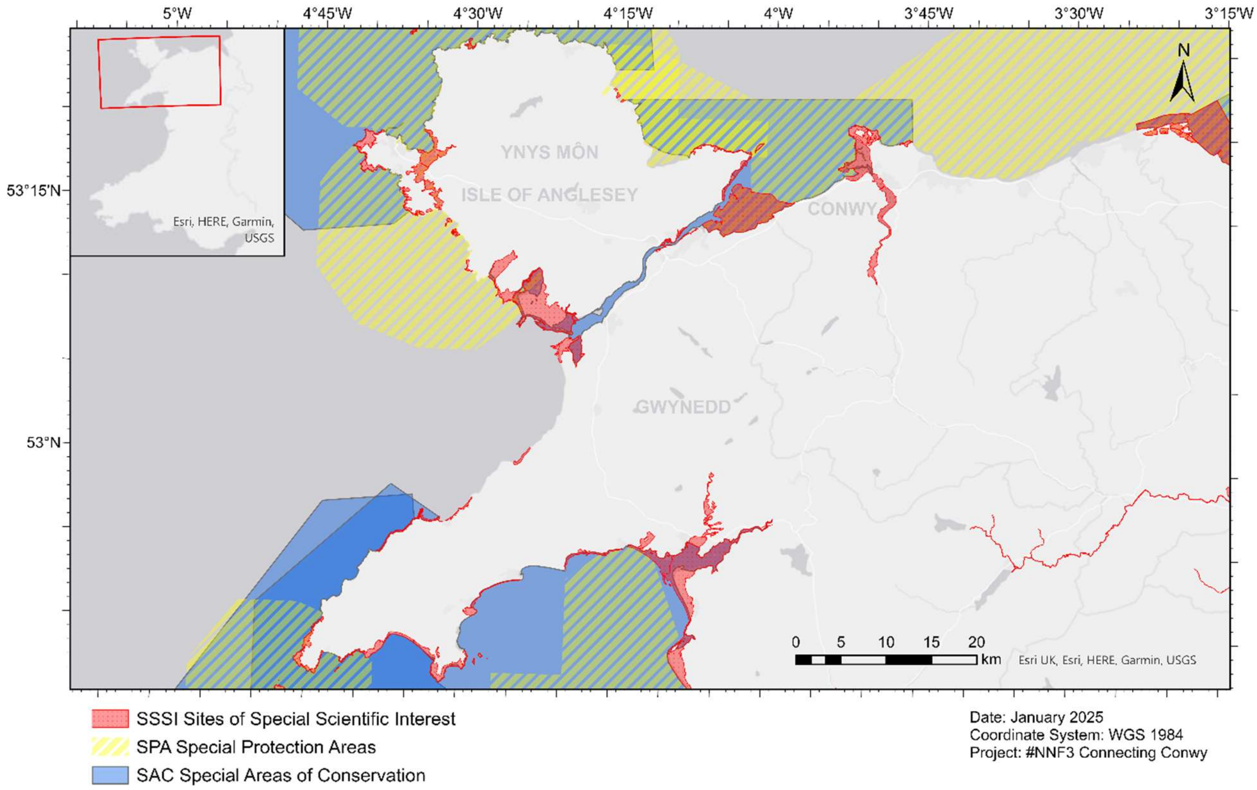

Figure 2. *Marine Protected Areas within and near the project region: Sites of Special Scientific Interest (red), Special Protection Areas (yellow striped), Special Areas of Conservation (blue). Contains Natural Resources Wales information © Natural Resources Wales and Database Right. All rights Reserved. Contains Ordnance Survey Data. Ordnance Survey Licence number AC0000849444. Crown Copyright and Database Right.*

The Menai Strait and Conwy Bay SAC extends from Menai Point in the west, to the Little Orme/ Rhiwledyn in the east, and Traeth Lligwy on Anglesey in the north (Figure 3). It was designated in 2004 under Article 4.2 of the Conservation of Natural Habitats and of Wild Fauna and Flora Directive (92/42/EEC) for five habitat features under Annex I as it is one of the best areas in the UK for the following:

- Sandbanks which are slightly covered by sea water all the time
- Mudflats and sandflats not covered by seawater at low tide
- Reefs

And supported a significant presence of:

- Large shallow inlets and bays
- Submerged or partially submerged sea caves

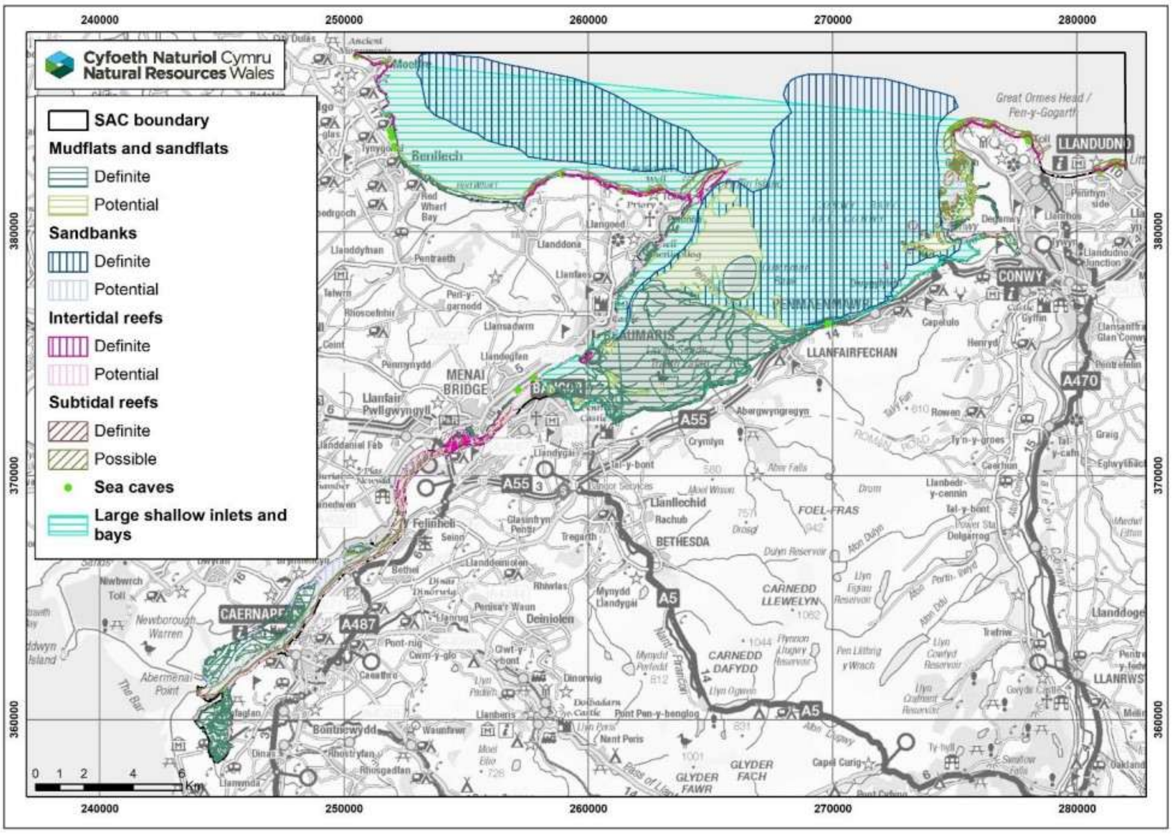

Figure 3. *Map of designated features of Y Fenai a Bae Conwy / the Menai Strait and Conwy Bay Special Area of Conservation (SAC). Source: Natural Resources Wales (Wynter et al., 2025b). Detailed maps for the features in Wales can be found on* *Data Map Wales*. *© Hawlfraint y Goron a hawliau cronfa ddata 2025 Arolwg Ordnans AC0000849444 © Crown copyright and database rights 2025 Ordnance Survey AC0000849444*

Recently conducted condition assessments for the designated features within the SAC reported only 1 out of 5 protected Annex I habitat features as favourable (see Table 1 from Wynter *et al.,* 2025b). It was also identified that the American slipper limpet *Crepidula fornicata* became established around 2019 in the Menai Strait and numbers are increasing substantially (Wynter *et al.,* 2025b). Water quality issues were identified, with five of the seven WFD waterbodies overlapping the SAC (Seiont, Foryd Bay, Anglesey North, Conwy Bay and Conwy) failing because of chemicals in the 2024 cycle 3 interim classification presence of nuisance algae in the watercourses was also recorded. Features within the SAC were also identified as definitely under threat of coastal squeeze and natural squeeze (loss of habitat against high ground) (Oaten *et al.,* 2024). The potential pressures from climate change on the SAC are unclear although research by Bangor University indicates that annual mean sea surface temperature is gradually rising in the Menai Strait (Smyth *et al.,* 2022). Targeted habitat restoration and management efforts are underway in some areas, offering a foundation for resilience and recovery to work towards meeting the conservation objectives (Table 2). Local Development Plans for Conwy and jointly for Anglesey and Gwynedd state the importance to conserve and enhance biodiversity and connectivity.

Marine feature condition assessments in NRW consist of selecting performance indicators for the feature, gathering the best available evidence to assess those indicators and conducting the assessment. The performance indicators were assessed using a combination of data from NRW Habitats Regulations monitoring, Water Framework Directive (WFD) Regulations 2017 (WFD Regulations) monitoring, commissioned evidence reports, scientific literature, plan and project assessments, external monitoring databases (e.g. National Biodiversity Network) and expert judgement.

***Table 1**. Summary of condition assessments for the designated features of Y Fenai a Bae Conwy / the Menai Strait and Conwy Bay Special Area of Conservation (SAC). Source: Natural Resources Wales (Wynter et al., 2025b).*

Feature	Condition assessment	Confidence in assessment
Mudflats and sandflats not covered by seawater at low tide	Favourable	Low
Reefs	Unfavourable	Medium
Sandbanks which are slightly covered by seawater all the time	Unfavourable	Medium
Large shallow inlets and bays	Unfavourable	Medium
Submerged or partially submerged sea caves	Unknown	Not applicable

***Table 2.** The conservation objectives for each designated feature of Y Fenai a Bae Conwy / the Menai Strait and Conwy Bay Special Area of Conservation (SAC). Data source: Natural Resources Wales (Wynter et al., 2025b).*

Feature	Objective
Mudflats and sandflats not covered by seawater at low tide	1. The overall distribution and extent of the mudflats and sandflats feature within the SAC and each of its main component habitats are stable or increasing, subject to natural change. 2. The hydro-morphological and chemical structure necessary for the function of the mudflats and sandflats feature are stable or improving, subject to natural change. 3. The abundance, distribution and diversity of communities and component habitats necessary for the structure and function of the mudflats and sandflats feature are stable or improving, subject to natural variability.
Reefs	1. The overall distribution and extent of the reefs feature within the SAC and each of its main component habitats are stable or increasing, subject to natural change. 2. The hydro-morphological and chemical elements necessary for the structure and function of the reefs feature are stable or improving, subject to natural change. 3. The abundance, distribution and diversity of species within component habitats and communities necessary for the structure and function of the reefs feature are stable or improving, subject to natural variability.
Sandbanks which are	1. The overall distribution and extent of the sandbanks feature within the SAC is stable or increasing, subject to natural change.

slightly covered by seawater all the time	2. The hydro-morphological and chemical elements necessary for the structure and function of the sandbanks feature are stable or improving, subject to natural change. 3. The abundance, distribution and diversity of species within component habitats and communities necessary for the structure and function of the sandbanks feature are stable or improving, subject to natural variability.
Large shallow inlets and bays	1. The overall distribution and extent of the large shallow inlets and bays feature within the SAC and each of its main component habitats are stable or increasing, subject to natural change. 2. The hydro-morphological and chemical elements necessary for the structure and function of the large shallow inlets and bays feature are stable or improving, subject to natural change. 3. The abundance, distribution and diversity of species within component habitats and communities necessary for the structure and function of the large shallow inlets and bays feature are stable or improving, subject to natural variability.
Submerged or partially submerged sea caves	1. The overall distribution and extent of the sea caves feature within the SAC are stable subject to natural change. 2. The hydro-morphological and chemical elements necessary for the structure and function of the sea caves feature are stable or improving, subject to natural change. 3. The abundance, distribution and diversity of communities and habitats necessary for the structure and function of the feature are stable or improving, subject to natural variability.

3.2 Pressures and Management

A range of operations occur in the SAC which may cause deterioration or disturbance to the protected features such as marina/harbour dredging, hard coastal defences, pipelines and cabling, surface runoff, fishing (trawling, dredging, netting, potting, line, hand-gathering, bait collection, aquaculture), and recreational activities including wildfowling, boating etc. (NRW, 2025b).

The region has served as a site for shellfish harvesting since prehistoric times. Today, Traeth Lafan, Traeth Melynog and Red Wharf Bay are significant regulated commercial cockle fisheries under the *Cockles and Mussels (Specified Area) (Wales) Order 2024 (S.I. 2011/1988)*, where traditional hand-gathering methods are employed. The fishery only opens when there is a sufficient stock of cockles to support sustainable harvesting without negatively affecting oystercatchers, for whom cockles are a primary food source. The fishery is now managed through a permitted fishery and the number of fishers is deemed to not be having a detrimental impact on the curlew prey habitat or to cause concerns about food availability for oystercatchers.

Natural mussel beds occur towards the western end of Traeth Lafan, between the River Ogwen and Glan y Mor Elias. A large, bottom culture/seabed lay mussel fishery exists within parts of the intertidal mudflats and sandflats feature on Traeth Lafan. The Fishery Order was in place when the SAC was designated, and the habitat was highlighted as 'modified' from the outset. Countryside Council for Wales; now Natural Resources Wales (NRW), acknowledged this habitat modification and confirmed that restoration of these intertidal areas would not be pursued. Since then, the extent of the fishery has remained largely unchanged. An artisanal hand-rake blue mussel fishery operates in Conwy estuary with Protected Designation of Origin status by the European Commission.

Mussel fisheries within the SAC and around the UK have reported reduced mussel landings and strong variability in annual recruitment success (Curtin, 2022; 2025; EIFCA, 2024; Scottish Government, 2025b; Burrows *et al.,* 2025). A historical study of mussel beds in Scotland found that 51% of historical mussel beds were reported as exhausted or destroyed by 1900s (Heard *et al.,* 2025). The drivers for the decline of blue mussels across Western Europe remains unknown but some evidence suggests that mussel beds are under severe environmental stress due to climate change, poor water quality and pollution events, sediment disturbance causing dislodgement and effecting filter feeding efficiency may have contributed to the decline of *M. edulis* populations (Beyer *et al.,* 2017; Kamermans and Saurel, 2022; OSPAR Commission, 2023; Heard *et al.,* 2025).

INNS threaten local marine life by predating on or out-competing native species for food, shelter and space. INNS can also facilitate the spread of disease and interfere with the genetic integrity of native species (hybridisation etc.). Welsh Government has legislation in place aiming to prevent the spread or introduction of INNS into Welsh waters. The Marine Strategy Framework Directive (MSFD) includes a UK monitoring and surveillance list for marine non-native species developed by CEFAS in 2015 to focus efforts on 'priority' marine species, representing those that do or could have a high environmental impact. The Marine Invasive Non-native Species Priority Monitoring and Surveillance List for Wales includes the INNS species listed on the MSFD which are present in Wales or require close surveillance, and those listed under the Wildlife and Countryside Act 1981, the Water Framework Directive and UKTAG Aquatic alien species. Locally, the Bangor Mussel Production Association and the CCW (now NRW), agreed upon and signed the Code of Good Practice to reduce the risk of invasive, non-native species to the Menai Strait and the potential impact on the mussel fisheries (Wilson and Smith, 2008; MacAlister, 2010).

3.3 Importance to improve the condition and connectivity

3.3.1 Oysters

Under the Habitats Directive, European oyster reefs are considered part of the Annex I habitat type "Reefs," but the species itself is not listed in Annex II qualifying species for SAC designation- Council Directive 92/43/EEC 1992/2013 (Council of the European

Communities, 1992); EUNIS 2025 (European Environment Agency, 2025). Within the Menai Strait and Conwy Bay SAC, the qualifying features are limestone reefs, sandbanks and the range of habitats comprising the large shallow inlets and bays feature, which support bivalve filter-feeding communities where oysters could occur (JNCC Standard Data Form UK0030202). Besides being present historically, native oysters could not be included in the site citation as the site was designated based only on the features present at the time of designation. Restoration of oyster populations could enhance the abundance, distribution and diversity of communities and habitats necessary for the structure and function of the protected features, improving ecosystem functioning within the SAC. Oysters and other bivalves are an important food source for marine bird communities. For example, *Ostrea edulis* was principal food source of oystercatcher historically, until oysters became more scarce and birds substituted for mussels (Dewar, 1922).

3.3.2 Mussels

Natural mussel beds occur towards the western end of Traeth Lafan, between the River Ogwen and Glan y Mor Elias. A large, bottom culture/seabed lay mussel fishery exists within parts of the intertidal mudflats and sandflats feature on Traeth Lafan. The Fishery Order was in place when the SAC was designated, and the habitat was highlighted as 'modified' from the outset. Countryside Council for Wales; now Natural Resources Wales (NRW), acknowledged this habitat modification and confirmed that restoration of these intertidal areas would not be pursued. Since then, the scale and extent of the fishery has remained largely unchanged.

- Mussels listed on the OSPAR Convention list of 'threatened and/or declining species and habitats' in the North-East Atlantic.
- Mussels food source of protected bird species- wildfowl and waders
- Landings of mussels locally reduced over recent decades
- The reefs feature of the Menai Strait and Conwy Bay SAC includes many different types of reefs, ranging from rocky to clay outcrops to 'biogenic' reefs formed by mussels. Naturally formed blue mussel beds *Mytilus edulis* are considered important habitat within the SAC

3.3.3 Seagrass

Although seagrass meadows in North Wales are not designated as standalone Special Areas of Conservation (SACs), they are encompassed within several Annex I habitat types under the EU Habitats Directive, including 'mudflats and sandflats not covered by seawater at low tide', 'estuaries', 'sandbanks', and 'large shallow inlets and bays'. In Wales, seagrass beds formed by *Zostera marina* and *Zostera noltii* are recognised as important sub-features within five SACs, where they contribute significantly to the ecological integrity of these wider habitats (NRW, 2025a).

Seagrass beds are also recognised in other policy frameworks. They are listed as habitats of principal importance under Section 7 of the Environment (Wales) Act 2016 and are considered threatened and declining under the OSPAR Convention. In addition, intertidal *Zostera spp.* beds are designated features of several Sites of Special Scientific Interest (SSSIs). Nine sites in Wales explicitly list seagrass, including Beddmanach-Cymyran and Traeth Lafan, see Table 3 (Welsh Government, 2018). Notable examples of extensive seagrass communities occur within the Pembrokeshire Marine / Sir Benfro Forol SAC and the Severn Estuary SAC (Wales Biodiversity Partnership, 2025).

These designations reflect the crucial ecological roles of seagrass meadows, which include supporting biodiversity, stabilising sediments, and sequestering carbon. However, because they are typically embedded within larger habitat features rather than designated as Annex I habitats, their protection can be inconsistent. Strengthening the condition and connectivity of the protected site network is therefore essential to ensure the resilience of Welsh seagrass ecosystems.

Table 3. *Summary of Welsh sites where seagrass (Zostera spp.) has been reported. Information includes statutory conservation designations, recorded Zostera species, and associated ecological or management features.*

Site	Designation	Seagrass species	Site features
Traeth Lafan	SSSI, SPA, within Menai Strait and Conwy Bay SAC, and a Local Nature Reserve. Seagrass beds are listed as a feature of the SSSI (Welsh Government, 2018; Armstrong *et al.,* 2021; NRW, 2025a).	*Zostera noltii*	Occurs in sheltered mud and sand habitats between Glan y Môr Elias and Pwll Budr culvert Wynter *et al.,* 2025b). These meadows support a diverse assemblage of organisms, including marine worms and sandeels, highlighting their role in sustaining local biodiversity (Jackson-Bué *et al.,* 2025a; 2025b; NRW, 2025a;).
Y Foryd	SSSI, within Menai Strait and Conwy Bay SAC	*Zostera noltii*	Water Framework Directive data reported the increasing of seagrass, giving High status in the last 2024 cycle 3 interim classification (Jackson-Bué *et al.,* 2025a; 2025b; Wynter *et al.,* 2025b).

Beddmanarch – Cymyran	SSSI	*Zostera noltii, Zostera marina*	Seagrass in sheltered waters of the Inland Sea, low suspended sediments, low level of nutrients (N,P,K) (CCW, 1986a)
Burry Inlet and Loughor Estuary	SSSI, within the Bae Caerfyrddin ac Aberoedd/ Carmarthen Bay and Estuaries SAC	*Zostera noltii*	Seagrass support the stabilisation of sediments, sources organic matter, and creates shelter and surface for the anchoring of other species and food for wildfowl.
Glannau Rhoscolyn	SSSI, within Glannau Ynys Gybi SAC	*Zostera marina*	Seagrass is found in Borthwen, sheltered sandy bay (CCW, 2001a).
Milford Haven Waterway	SSSI, within Pen Llŷn a'r Sarnau/ Lleyn Peninsula and the Sarnau SAC	*Zostera noltii, Zostera marina*	Intertidal sandy/muddy areas supporting extensive seagrass beds (Joint Nature Conservation Committee, 2015; Jackson-Bué *et al.,* 2025a; 2025b)
Porth Dinllaen i Borth Pistyll	SAC	*Zostera marina*	The seagrass area expanded between 2004 and 2016 (Davies *et al.,* 2017; Jackson-Bué *et al.,* 2025a; 2025b)
Severn Estuary / Môr Hafren	SSSI	Zostera spp.	Habitat description not available (Joint Nature Conservation Committee, 2015).
Tiroedd a Glannau Rhwng Cricieth ac Afon Glaslyn	SSSI, MPA, within Pen Llŷn a'r Sarnau/ Lleyn Peninsula and the Sarnau SAC	*Zostera marina*	Seagrass presence in Tremadog Bay, uncommon habitat (Joint Nature Conservation Committee, 2015; UNEP-WCMC, 2025; Jackson-Bué *et al.,* 2025a; 2025b).
Twyni Chwitffordd, Morfa Landimor a Bae Brychdwn / Whiteford Burrows Landimore Marsh and Broughton Bay	SSSI, within Ardal Gwarchodaeth Arbennig Bae Caerfyrddin / Carmarthen Bay SPA, NNR, SAC	*Zostera noltii*	Seagrass bed cover tends to fluctuate within natural variability (Joint Nature Conservation Committee, 2015).

3.3.4 Saltmarsh

In Wales, saltmarshes are included as qualifying features within a number of coastal SACs, including Glannau Môn: Cors heli SAC and the Dee Estuary SAC, where they form integral components of the intertidal ecosystem and contribute to the ecological character of estuarine and coastal habitats (NRW, 2018a; 2018b; JNCC, 2015a; 2015b; 2015c; 2015d; 2015e; 2015f).

Saltmarshes as well as mudflats are in the Annex I section of the Habitats Directive and they are recognised in the Section 7 of the Environment (Wales) Act 2016 as ‘habitats of principal importance’. These habitats often represent a significant component of two broader habitat types: ‘estuaries’ and ‘large shallow inlets and bays’. In Wales, many mudflats and saltmarshes are additionally designated as features within Ramsar sites, Special Areas of Conservation (SACs), or Sites of Special Scientific Interest (SSSIs), and/or serve as supporting habitats for bird species that are qualifying features of numerous Special Protection Areas (SPAs) (Armstrong *et al.,*2021). A summary of Welsh sites where saltmarshes have been reported in Table 4.

These designations reflect the critical ecological functions of salt marshes, which include providing nursery grounds for fish, supporting diverse bird populations, buffering coastal flooding and erosion, and contributing to blue carbon storage. However, pressures such as coastal squeeze, grazing, and enrichment of nutrients in the water (eutrophication) continue to threaten salt marsh resilience in Wales. Strengthening protection and improving habitat connectivity within the marine protected area network is therefore essential to safeguard the long-term ecological role of Welsh saltmarsh ecosystems.

***Table 4**. Summary of Welsh sites where saltmarshes have been reported. Information includes statutory conservation designations, recorded saltmarsh species, and associated ecological or management features.*

Site	Designation	Saltmarsh species	Site features
Glannau Môn: Cors heli / Anglesey Coast: Saltmarsh	SAC	• *Juncus maritimus* • *Salicornia* spp • Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	In 2004, the site was designated under Article 4.2 of the Conservation of Natural Habitats and of Wild Fauna and Flora Directive (92/42/EEC) for five habitat features under Annex I (Jackson-Bué *et al.,* 2025c). *Salicornia* spp. and G*lauco-Puccinellietalia maritimae* occur on Malltraeth in the Cefni estuary lying either side of the dune systems at Newborough Warren (JNCC, 2015e; NRW 2018b).

Aber Mawddach / Mawddach Estuary	Within Pen Llŷn a'r Sarnau SAC SSSI	• Atlantic salt meadows Glauco-*Puccinellietalia maritimae* • Salicornia and other annuals colonising mud and sand • NNS: Japanese knotweed (*Fallopia japonica*) • NNS: *Gracilaria vermiculophylla* (Mercer and Brazier, 2023)	Section of the Mawddach saltmarsh between Morfa Friog and Morfa Mawddach were found to be heavily grazed (Lewis, 2011; JNCC, 2015c; Hatton-Ellis *et al.,* 2025)
Afon Tywi, Aber Taf / Taf Estuary, and Gwendraeth (Three Rivers estuaries)	Part of Carmarthen Bay and Estuaries SAC	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae*	Lost 5% of the extent, as result of erosion and possible presence of coastal squeeze. Plant communities are not currently assessed (Jackson-Bué *et al.,* 2025e).
Afon Teifi/ River Teifi	SAC, SSSI	• Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	Saltmarsh extent of 13.61 ha, 1.7% of % cover (JNCC, 2015a; 2015d).
Arfordir Pen-bre / Pembrey Coast	SSSI, part of Carmarthen Bay Dunes SAC	• Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	The back-barrier areas, once tidal flats and saltmarshes of the Gwendraeth Estuary, have been partially reclaimed over the past 300 years and now include Pembrey Airport and a motor racing circuit (Pye *et la.,* 2014).
Artro	SSSI, within Pen Llŷn a'r Sarnau SAC	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • *Salicornia* and other annuals colonising mud and sand	Identified opportunistic macroalgae withing the Salicornia feature, further data are required to identify the extent (JNCC, 2015c; Hatton-Ellis *et al.,* 2025)
Beddmanarch – Cymyran	SSSI	• Glasswort	Saltmarsh extent estimated to be 60 ha (CCW, 1986a).

		• Common saltmarsh grass • Thrift • Lax-flowered sea-lavender and sea rush *Juncus maritimus* • Golden samphire (occurring in saltmarsh communities and on parts of the rocky shoreline)	
Broadwater	SSSI	• Sea Rush *Juncus maritimus* • Wild Celery *Apium graveolens* • Lesser Centaury *Centaurium pulchellum* • Sharp Sea Rush *Juncus acutus*	Saltmarsh has been mentioned as important component of the site (NRW, SSSI_0166_Citation_EN0016c08).
Burry Inlet and Loughor Estuary	Part of the Carmarthen Bay SAC.	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • *Salicornia* and other annuals colonising mud and sand	Area subjected to overgrazing. Saltmarsh extent of 2,200 ha (Wynter *et al.,* 2025a).
Crymlyn Burrows	SSSI under Wildlife and Countryside Act in 1987 (Swansea University, 2018)	• Glasswort *Salicornia* spp. • Sea plantain • Thrift • Rock sea lavender • Red fescue • Common saltmarsh grass	Saltmarsh presence on the east side in the east side of the site: on the bank of the River Neath (Countryside Council for Wales, SSSI_1092_SMS_EN0015f6b).
Dee Estuary / Aber Afon Dyfrdwy	SAC, SPA	• Atlantic salt meadows *Glauco-*	Ongoing natural erosion of saltmarsh and mudflat has been observed, associated with the

		Puccinellietalia maritimae • *Salicornia* and other annuals colonising mud and sand • Sea-blite *Suaeda maritima* • Hybrid scurvy grass *Cochlearia x hollandica* • Saltmarsh-grass *Puccinellia maritima* • Sea aster *Aster tripolium* • Sea arrowgrass *Triglochin maritima*	channel's migration toward the Welsh shore (JNCC, 2021; NRW, 2018a).
Dyfi Estuary/ Aber Dyfi	SSSI, within Pen Llŷn a'r Sarnau SAC, SPA	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • NNS: Japanese knotweed (*Fallopia japonica*) • NNS: *Gracilaria vermiculophylla* (Mercer and Brazier, 2023)	Heavy grazing pressure in a section of the saltmarsh following local actor interviews conducted in 2022 (JNCC, 2015c; Hatton-Ellis *et al.,* 2025).
Dwyryd	Within Pen Llŷn a'r Sarnau SAC	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • *Salicornia* and other annuals colonising mud and sand • NNS: Japanese knotweed (*Fallopia japonica*) • NNS: *Gracilaria vermiculophylla*	Heavy grazing pressure following interviews with key actors conducted in 2022. Medium confidence on INNS and NNS targets, however NNS survey on saltmarshes are required (JNCC, 2015c; Hatton-Ellis *et al.,* 2025).

		(Mercer and Brazier, 2023)	
Y Fenai a Bae Conwy/ Menai Strait and Conwy Bay	SAC	• Atlantic salt meadows Glauco-Puccinellietalia maritimae	Including Traeth Lafan, the shores of the Menai Strait, and the Foryd estuary (JNCC, 2015f).
Glaslyn	Within Pen Llŷn a'r Sarnau SAC	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • *Salicornia* and other annuals colonising mud and sand • NNS: Japanese knotweed *Fallopia japonica* • NNS: *Gracilaria vermiculophylla* (Mercer and Brazier, 2023)	High abundance of *Salicornia spp.* While overgrazing pressure is happning (JNCC, 2015c; Hatton-Ellis *et al.,* 2025).
Gronant Dunes and Talacre Warren	SSSI	• Common cordgrass *Spartina spp.* • Range of pioneer and more established vegetation types	Tidal incursions occasionally reach the dune system located behind Talacre Lighthouse, sustaining a zone of saltmarsh vegetation (CCW, 2007).
Hook Wood	SSSI	No data available	Presence of upper saltmarsh plants (CCW, 1986b) and MPA associated to saltmarshes in the site (Oaten *et al.,* 2024).
Merthyr Mawr	SSSI	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • Sea-purslane *Atriplex portulacoides* • Glasswort *Salicornia* spp.	Saltmarsh is characterised by three discrete bays partitioned by sandbar formations (CCW, 2002).

		• Annual sea-blite *Suaeda maritima* • Sea arrowgrass *Triglochin maritima* • Common saltmarsh grass *Agrostis stolonifera* • Red fescue *Festuca rubra* • Rock sea-lavender *Limonium procerum* • Sand-couch *Elytrigia juncea*	
Milford Haven Waterway	Part of Pembrokeshire SAC	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae*	Evidence of opportunistic macroalgae growth on pioneer saltmarsh has been reported (JNCC, 2015d; Lock, 2021; Jackson-Bué *et al.,* 2025e). The extent of saltmarsh decreased by 0.87 ha between 2000 and 2020 (Jackson-Bué *et al.,* 2025e).
Morfa Harlech a Morfa Dyffryn	SSSI, Within Pen Llŷn a'r Sarnau SAC	• Glasswort *Salicornia* spp. • Thrift *Armeria maritima* • Common saltmarsh grass *Puccinellia maritima* • Sea milkwort *Glaux maritima* • Common cord grass *Spartina anglica* • Sea rush *Juncus maritimus* • Lax-flowered sea-lavender *Limonium humile* • Spiral tasselweed *Ruppia cirrhosa*	Lost approximately 5% of the extent. The former saltmarsh extent is now sandflat, further assessments are needed to verify presence (JNCC, 2015c). Plant community from CCW, 2001b.

		• Dwarf spike rush *Eleocharis parvula* • Mudwort *Limosella australis*	
Oxwich Bay	SSSI	• Sea lavender *Limonium* spp. • Thrift *Armeria maritima* • Sea-purslane *Atriplex portulacoides* • Glasswort *Salicornia europaea agg.* • Common saltmarsh grass *Puccinellia maritima*	The saltmarsh exhibits a clear zonation, progressing from mid-marsh communities to a transitional zone at the dune margin (CCW, 1984).
Pennard Valley	SSSI	• Rock sea-lavender *Limonium binervosum*	Lightly grazing pressure (CCW, 1987).
Severn Estuary/ Môr Hafren	SAC	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • Spartina swards *Spartinion maritimae*	Area covered by Atlantic salt meadows *Glauco-Puccinellietalia maritimae* is 656.06 ha (JNCC, 2015b).
Twyni Chwitffordd, Morfa Landimor a Bae Brychdwn / Whiteford Burrows, Landimore Marsh and Broughton Bay	NNR, SPA, SAC, SSSI	• Atlantic salt meadows *Glauco-Puccinellietalia maritimae* • Thrift *Armeria maritima* • Common cordgrass *Spartina anglica* • Common glasswort *Salicornia europaea agg.*	Heavy grazing pressure impacting features and structure of the saltmarsh (Jackson-Bué *et al.,* 2025e).

		- Annual sea-blite *Suaeda maritima* - Sea aster *Aster tripolium* - Sea plantain *Plantago maritima* - Saltmarsh rush *Juncus gerardii* - Sea rush *Juncus maritimus* - Common saltmarsh grass and creeping bent *Agrostis stolonifera* - Round-fruited rush *Juncus compressus*	
Tywyn Aberffraw	Anglesey Coast: Saltmarsh SAC	No data	Maps of distribution and extent from 1997-1998 (Prosser and Wallace, 1999) considered outdated (Jackson-Bué *et al.*, 2025e).

4. Governance and Local Actor Context

A wide range of organisations, partnerships, community groups, research institutions and industry actors are active within, or closely connected to, the Menai Strait and Conwy Bay region. These groups collectively contribute to marine habitat management, biodiversity monitoring, restoration trials, aquaculture, community engagement, and evidence provision. Understanding the roles of local actors is essential for delivering the aims of the *#NNF3 Connecting Conwy* project with ongoing work, avoiding duplication, and ensuring community-led, collaborative seascape-scale recovery.

There are key local organisations actively engaged in marine conservation, management, monitoring, and community representation. Several regional and local partnerships are actively engaged with issues concerning marine habitat resilience, coastal management, and restoration. The region benefits from a wide range of past and ongoing restoration, monitoring, aquaculture and research projects that provide a strong foundation for the *Connecting Conwy* initiative, see Table 5.

Table 5. *Summary of the key local organisations, partnerships, initiatives and projects (past and present) engaged in marine conservation, management, fisheries, monitoring, research and community representation.*

Organisation / Initiative	Sector	Primary Role / Relevance
Bangor Mussel Producers Association	Industry / Aquaculture	Represents commercial mussel producers (including Deepdock Ltd, Myti Mussels Ltd, Extramussel Ltd and Ogwen Mussel Ltd); key partners in aquaculture management and habitat restoration discussions.
Bangor University	Research / Academic	Conducts research on aquaculture, blue carbon, invasive non-native species (INNS), hydrodynamics, biodiversity and habitat suitability modelling; leads several regional monitoring and restoration projects.
Bionet Local Nature Partnership	Partnership / Governance	Biodiversity partnership that strengthens collaboration among community groups, practitioners, landowners and local authorities in Conwy.
Coastal and Seas Partnership Cymru	Partnership / Governance	National partnership improving collaboration and resilience across Welsh coasts and seas.
Conwy Mussel Fishery	Industry / Fisheries	Artisanal hand-raked mussel fishery relevant to sustainable harvesting and habitat management.
Conwy River Citizen Science Project	Research / Citizen Science	Bangor University-led initiative monitoring water quality and pathogens in the River Conwy catchment.

Organisation / Initiative	Sector	Primary Role / Relevance
Environment Platform Wales Blue Carbon Forum	Research / Knowledge Exchange	Connects researchers, policymakers and practitioners working on blue carbon habitats and coastal ecosystem recovery.
Joint Nature Conservation Committee (JNCC) Habitat Suitability Models	Research / Government	Provides national habitat suitability models for seagrass and other marine habitats.
Local Nature Partnership	Partnership / Governance	Coordinates biodiversity protection and enhancement projects across Ynys Môn.
Local Nature Partnership	Partnership / Governance	Coordinates local organisations and communities to support nature recovery in Gwynedd.
Marine Conservation Society – Atlantic Coast Programme	NGO / Restoration	Supports a network of community-based marine habitat restoration projects across the UK Atlantic coast.
Menai Oysters and Mussels	Industry / Aquaculture	Local shellfish producer involved in oyster and mussel cultivation and management.
Menai Strait Fishery Order Management Association (MSFOMA)	Governance / Fisheries Management	Governs shellfish management and engagement under the Menai Strait Fishery Order.
Menai Strait Partnership Forum	Partnership / Governance	Forum between different parties, coordinating coastal management, aquaculture, navigation and environmental issues.

Organisation / Initiative	Sector	Primary Role / Relevance
Natur am Byth!	NGO / National Programme	National species and habitat recovery programme supporting marine biodiversity projects, including oysters and seagrass.
Native Oyster Network UK & Ireland	Network / Research	Collaborative network sharing best practice and evidence for native oyster restoration.
Natural Resources Wales	Regulatory / Statutory Agency	Environmental regulator responsible for marine monitoring, assessments, permitting, biosecurity and technical advice.
North Wales Rivers Trust	NGO / Catchment Management	Delivers water quality monitoring and catchment restoration; hosts the Menai Strait Partnership Forum.
North Wales Wildlife Trust	NGO / Conservation	Leads Shoresearch, invasive species monitoring, seagrass restoration and public outreach.
PLAS SAC Biosecurity Plan	Governance / Biosecurity	Partnership framework for invasive species prevention and response within the SAC.
Project Seagrass	NGO / Research	Specialist seagrass conservation charity delivering restoration, monitoring and community engagement.
Project SIARC	NGO / Research / Citizen Science	Collaborative initiative linking fishers, researchers and communities to safeguard sharks, skates and rays.
Saltmarsh Network Cymru	Network / Research	Facilitates evidence sharing, monitoring and management collaboration for saltmarsh habitats.

Organisation / Initiative	Sector	Primary Role / Relevance
Sea Watch Foundation	NGO / Research	Marine mammal conservation charity delivering monitoring and citizen science, including the Caru'r Cefni project.
Seagrass Network Cymru	Network / Conservation	Coordinates implementation of the National Seagrass Action Plan across Wales.
Seagrass Ocean Rescue	Restoration Project	Major seagrass restoration programme led by Project Seagrass and partners.
Seasearch	Citizen Science / Research	Trains volunteer divers and snorkellers to collect marine biodiversity data.
The Crown Estate	Governance / Landowner	Manages the seabed and much of the foreshore, including leasing for aquaculture and marine infrastructure.
The Wild Oysters Project: Conwy Bay	Restoration Project	Community-based native oyster restoration programme led by ZSL and Bangor University.
Tir a Môr Education Pack	Education / Outreach	Educational resource linking schools and communities with coastal ecosystems and land–sea connections.
Wales Native Oyster Restoration Action Plan	Governance / Strategic Planning	NRW-led roadmap guiding native oyster restoration through collaboration, policy and best practice.
Welsh Fishermen's Association	Industry / Fisheries Representation	Represents commercial fishers and provides input on fisheries interactions and restoration impacts.

Organisation / Initiative	Sector	Primary Role / Relevance
Welsh Government	Governance / Policy	Responsible for marine policy, fisheries management and marine spatial planning.
Y Môr a Ni	Education / Ocean Literacy	National ocean literacy framework strengthening public connection with Welsh coasts and seas.
Zoological Society of London	NGO / Research	Leads the Connecting Conwy Project and supports oyster restoration, citizen science and marine conservation initiatives.

5. Marine habitats: Ecology, Condition and Suitability Evidence

5.1 European flat oyster, *Ostrea edulis*

5.1.1 Habitat Overview and Ecological Importance

The native oyster, or the European flat oyster (*Ostrea edulis*), is a temperate bivalve species, which settles on hard substrate, such as rock or shell (Perry and Jackson, 2017; Smyth *et al.,* 2018). When found in high densities, this species can act as an ecosystem engineer, forming complex, three-dimensional biogenic reefs (Morris *et al.,* 2019).

These reefs function as an important sheltering, feeding, and nursery habitat for marine species, including commercial fish species (Peterson *et al.,* 2003). Native oyster reefs also provide ecosystem services which are vital for environmental and human wellbeing (Thomas *et al.,* 2022). These include coastal protection through slowing wave and storm surge energy, improved water quality and clarity through the oyster's filter feeding efficiency and contributing to blue carbon cycling, see Figure 4 (Albentosa *et al.,* 2023; Coen *et al.,* 2007; Lee *et al.,* 2020).

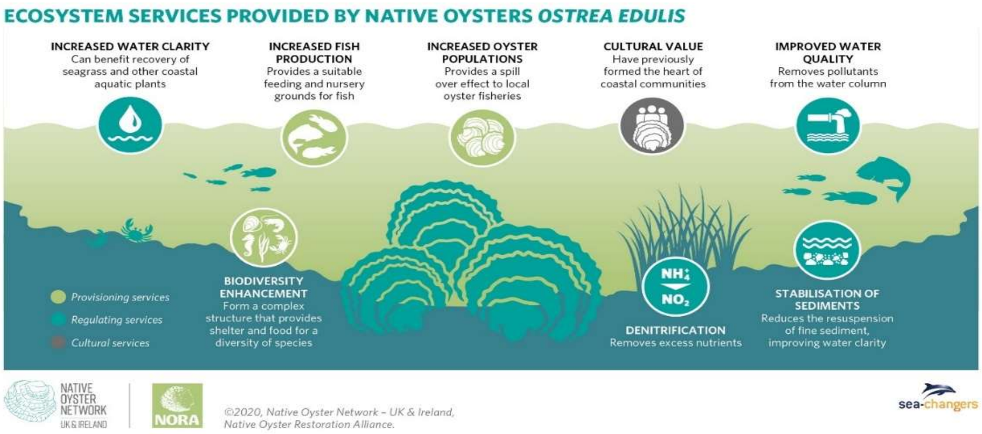

Figure 4. *Infographic illustrating the ecosystem services provided by native oyster (Native Oyster Network – UK & Ireland; Native Oyster Restoration Alliance, 2020) © Native Oyster Network – UK & Ireland / NORA.*

Populations of native oyster were once found in high densities around the British Isles and Europe and were a dominant marine habitat associated with estuaries, bays, sheltered inlets, sea locks/loughs/fjords and coastal open seas. Historical populations had an average reef size of 30ha (Thurstan *et al.,* 2024). Historically, Wales was home to prolific oyster fisheries with large beds in Puffin Island, Red Wharf Bay, Rhoscolyn and Llanddwyn Islands, Caernarfon and various sites along the Llŷn Peninsula (Hayden-Hughes *et al.,* 2023). However, in the UK native oyster reefs have declined by 95% since the mid-19th century (Beck *et al.,* 2011), with the ecosystem recently classed as functionally collapsed under the IUCN Red List of Ecosystems Framework (zu Ermgassen *et al.,* 2024). Despite this severe decline, remnant populations remain in parts of Welsh waters, including in Milford Haven and Swansea Bay (Hayden-Hughes *et al.,* 2023).

The key drivers that have contributed to the decline in native oyster populations, include a combination of disease, poor water quality including nutrient pollution, habitat loss, historic overfishing, and competition with invasive non-native species (Herbert *et al.,* 2016; Helmer *et al.,* 2019; Jeppesen *et al.,* 2018; Mori, 1979; Pouvreau *et al.,* 2023; Sas *et al.,* 2020). Native oyster reefs are also subjected to the effects of climate change, including sea level rise, increased storm severity and occurrences, rising sea temperatures and ocean acidification (Gazeau *et al.,* 2013; Gilson *et al.,* 2021; Helmer *et al.,* 2019; Kyzar *et al.,* 2021; Munroe *et al.,* 2013). Given their significant decline and ongoing threats, restoring native oyster habitat is required to increase habitat extent and connectivity, contributing towards restored ecosystem function and delivery of ecological and societal benefits to coastal waters. Table 6 summarises the abiotic and biotic habitat suitability characteristics at different life stages for *O. edulis,* adapted from Preston *et al.,* 2020.

Table 6. *Abiotic and biotic habitat suitability characteristics, relevance to various life-history processes and their ranges for the European native oyster (Ostrea edulis). Based on Smaal et al., (2017) where information is available. (Sourced from Preston et al., 2020.)*

ABIOTIC & BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT	RANGE
Sediment composition				X	Fine sand (> 63µm) and firm silty sand or silty gravel. All with shells and stones.
Suspended sediment (mg/l)		X			< 60
Temperature winter, Tmin (°C)	X				> 3
Temperature summer, Tmax (°C)			X		< 30
Oxygen conditions (mg/l)	X				> 3.5
Salinity (PSU or ppt)	X				25- 35
Food concentration (chl*a* in µg/l)		X			Growth > 0.5, Gonad development > 1.68
Larval retention				X	Larvae must remain near point of release.
Predation	X				High numbers of predators can decimate a population.
Competition		X			Competition for food can reduce growth and reproduction.
Water Depth	X				Intertidal – 80m
Current velocity (m/s)				X	0.25-0.8
Bed shear stress (tau N/m²)	X				Average < 1, Max < 10
Sea Bed mobility (cm/day)	X				< 0.8

5.1.2 Habitat suitability and modelling review

There is increasing interest in the restoration and recovery of native oysters and habitat suitability mapping has been applied to nearshore and offshore environments around the UK, and Europe (Pogoda *et al.,* 2023; Stechele *et al.,* 2023). In Scotland, the Marine Directorate analysed environmental data to identify areas unsuitable for restoration (Scottish Government, 2025a). They mapped locations based on key environmental thresholds affecting oyster survival and reproduction. Areas were considered unsuitable if they exceeded certain limits: depth greater than 80 m, current speed above 0.45 m/s, or substrate silt content over 75%. Temperature was also a factor, with two thresholds used to reflect differences between oyster populations—areas where maximum temperatures stay below 13 °C or 15 °C were deemed unsuitable. The analysis covered all of Scotland at a 1 km resolution, with a more detailed assessment for the Orkney region.

Localised studies have been completed in Ireland such as in Galway Bay. Pereiro *et al.,* 2025, combined habitat suitability modelling with laboratory experiments measuring oyster mortality under different temperature and salinity conditions. A Habitat Suitability Index was developed to predict how oysters respond to environmental conditions over time in relation to climatic pressures.

In addition to the abiotic factors typically included in habitat suitability modelling, socio-economic and logistical factors are also important to consider (Hughes *et al.,* 2023). In 2024, the Environment Agency (EA) published a spatial dataset identifying potential areas for native oyster (*Ostrea edulis*) restoration in England. Unlike earlier habitat suitability models based on statistical prediction, this dataset represents a rule-based spatial analysis combining multiple environmental datasets and expert input to identify areas of potential native oyster bed occurrence. Outputs of the dataset are presented as mapped polygons of "Native Oyster Bed Potential Areas", including subsets of 'preferred' and 'additional' sites (see Figure 5). The dataset provides a high-level, national-scale indication of suitability rather than a probabilistic output, and is intended as an initial screening tool for restoration planning.

The dataset was derived through the integration of multiple spatial data sources, including:

- EMODnet current energy models (2016)
- Natural England Marine Habitats and Species Open Data
- JNCC EUNIS Level 3 seabed habitat map and EUSeaMap model outputs
- Environment Agency intertidal layers and Water Framework Directive water body boundaries

The key environmental predictor variables used to define potential habitat include:

- Seabed substrate type (broadscale habitat classification)
- Current energy at the seabed

- Coastal proximity (typically within ~1 nautical mile)
- Exclusion of intertidal areas

Selection criteria were based on known habitat preferences for native oysters, informed by the Marine Life Information Network (MarLIN), specifically:

- Low current energy conditions (<130 N m^{-2}, based on long-term averages)
- Presence of subtidal mixed sediments (EUNIS Level 3: A5.4)

Following initial model outputs from 2019, the dataset was refined through a series of spatial filters and expert judgement, including:

- Removal of areas <1 ha in size
- Exclusion of areas near major ports
- Clipping to defined coastal water bodies
- Identification of "preferred sites" with minimal overlap with pressures (e.g. dredging or infrastructure)
- Inclusion of "additional sites" identified through consultation with local experts

The key variables influencing the identification of potential native oyster habitat were seabed substrate and hydrodynamic conditions, particularly low current energy environments associated with stable, mixed sediments. These conditions are critical for larval settlement and reef persistence. The inclusion of "preferred sites" further highlights the importance of anthropogenic pressures in determining restoration feasibility, recognising that environmental suitability alone does not guarantee successful habitat establishment.

It is important to note that the dataset provides a broad-scale, strategic indication of potential habitat and does not account for all ecological or operational constraints. Local-scale validation and site-specific assessments remain necessary, and suitable areas may also exist outside those identified within the dataset.

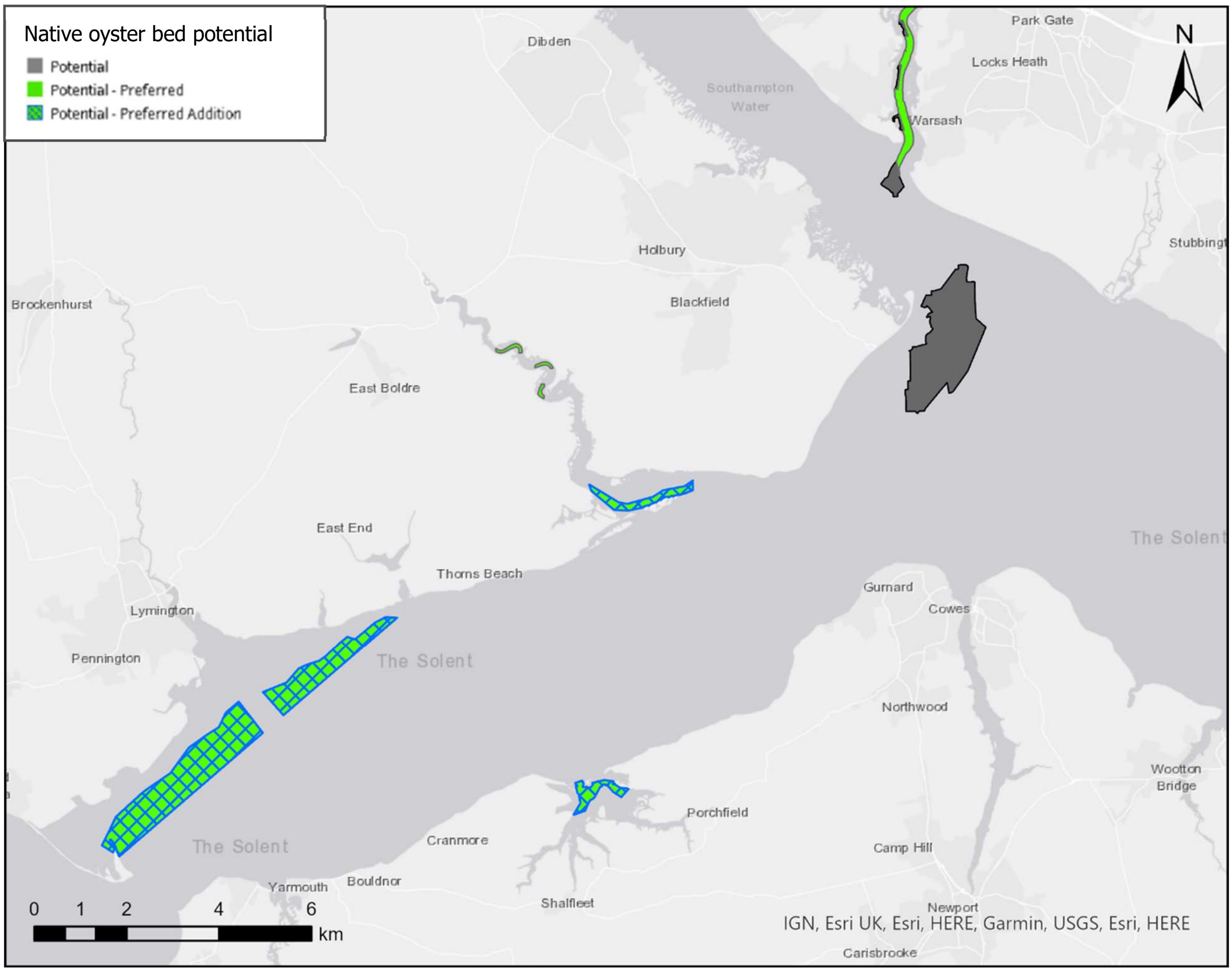

Figure 5. *A map of The Solent on the south coast of England as an example of the Native oyster bed potential areas using the datalayer for England published by Environment Agency in 2024. Areas have been refined to identify "preferred" sites with minimal overlap with pressures and "additional" sites identified through consultation with local experts. © Environment Agency copyright and/or database right 2020. All rights reserved.*

In Wales, Natural Resources Wales (NRW) published in 2026 a spatial assessment identifying opportunities for the restoration of native oyster (*Ostrea edulis*) habitats in Welsh waters (Figure 6). It has been developed as part of the Wales Native Oyster Action Plan.

The dataset was developed as part of a wider programme to identify restoration opportunities for native oysters in Welsh waters. Building on work undertaken by ABPMer for Natural Resources Wales (NRW), with additional refinement by NRW specialists, the model used a structured, rule-based spatial analysis to map areas with environmental conditions considered suitable for oyster settlement and survival. Rather than applying a probabilistic habitat suitability model, the approach combined environmental datasets with expert judgement to delineate potential restoration areas.

The methodology followed a multi-stage process:

- Review of published literature and existing evidence on the environmental requirements of native oysters
- Compilation and assessment of relevant spatial datasets covering hydrodynamic conditions, bathymetry, and seabed habitat
- Definition of environmental thresholds and habitat criteria through expert consultation
- Creation of a composite suitability layer identifying areas meeting all specified conditions
- Inclusion of additional inshore areas where the source datasets were too coarse in resolution and where suitability was confirmed by NRW specialists

The predictor variables (environmental datasets) used in the model include:

- Current energy from EMODnet, with suitable areas defined as those with hydrodynamic energy below 130 N m^{-2}
- Bathymetry from GEBCO, limited to water depths shallower than 80 m
- Seabed habitat from the Joint Nature Conservation Committee (JNCC) UKASH combined habitat map, selecting subtidal mixed, coarse, and macrophyte-dominated sediments

The suitability layer was generated by applying these environmental thresholds and combining the resulting spatial layers. Areas were considered suitable where all criteria were met, indicating the presence of appropriate depth, hydrodynamic conditions, and seabed habitat for oyster establishment.

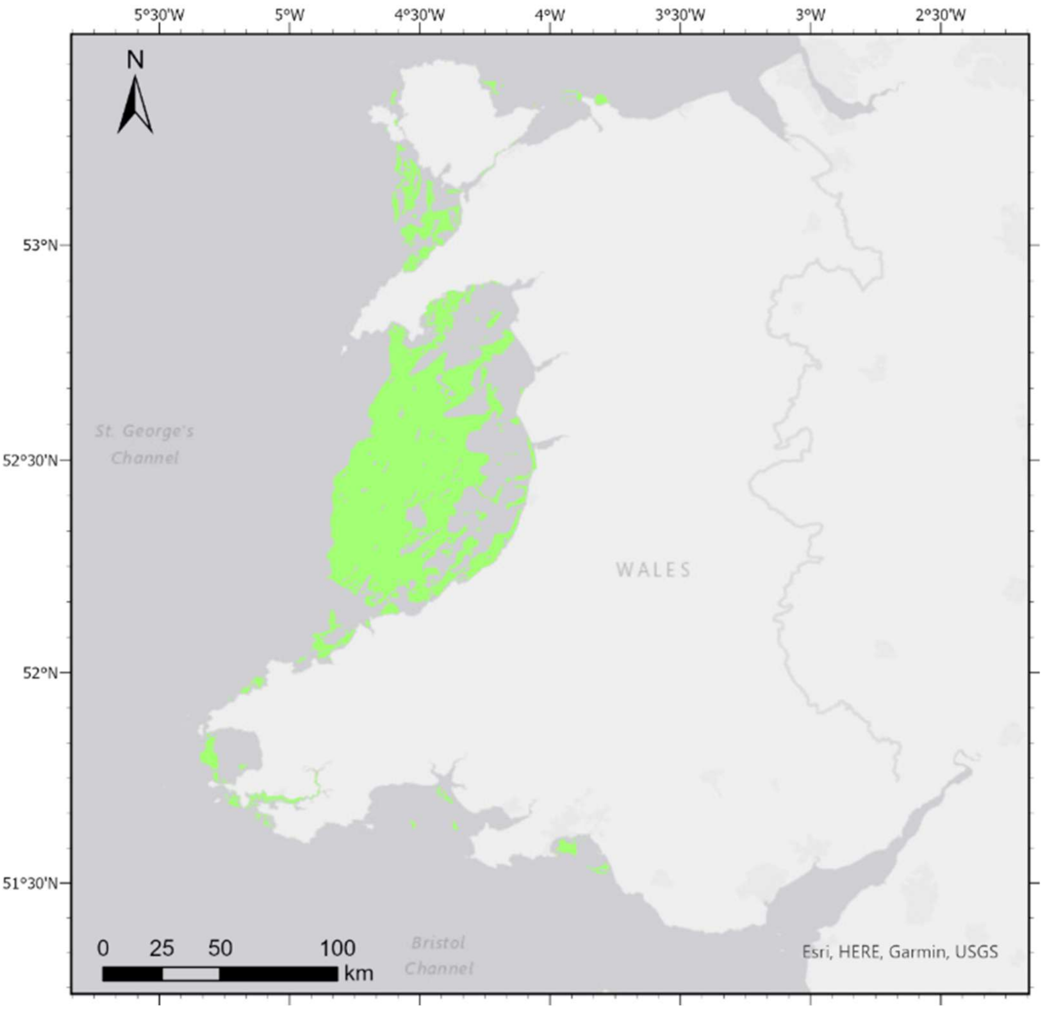

Figure 6. *Native oyster potential restoration areas in Wales (within the model extent of 0 to 80 m depth) from NRW, 2026. Contains Natural Resources Wales information © Natural Resources Wales and Database Right. All rights Reserved. This includes some information based on data provided by: © European Union, 1995-2026. Copyright © 2020-2026, GEBCO. © JNCC and other data providers as set out in their data inventory.*

The work built on a previous project mapping restoration potential completed by ABPmer for NRW for six marine and coastal habitats (Armstrong *et al.,* 2021), including native oyster (Figure 7). This approach used environmental datasets, historic records, and expert input to identify opportunity areas. Key factors included water depth (0–80 m), low tidal energy (current speeds below 1 m s^{-1}), suitable seabed substrate, and wave energy. Oyster occurrence records were sourced from the Ocean Biodiversity Information System (OBIS) and the National Biodiversity Network (NBN) Atlas, while environmental data were derived from EMODnet and Joint Nature Conservation Committee (JNCC) habitat maps.

The outputs comprise spatially explicit maps highlighting areas of potential suitability for native oyster restoration across Welsh waters. These are intended to support strategic planning and prioritisation of restoration efforts, rather than provide definitive predictions of habitat presence.

As with similar large-scale opportunity mapping exercises, the dataset does not incorporate all ecological and biological constraints (e.g. larval supply, disease, or historical depletion) and therefore should be used alongside site-specific surveys and local expert knowledge.

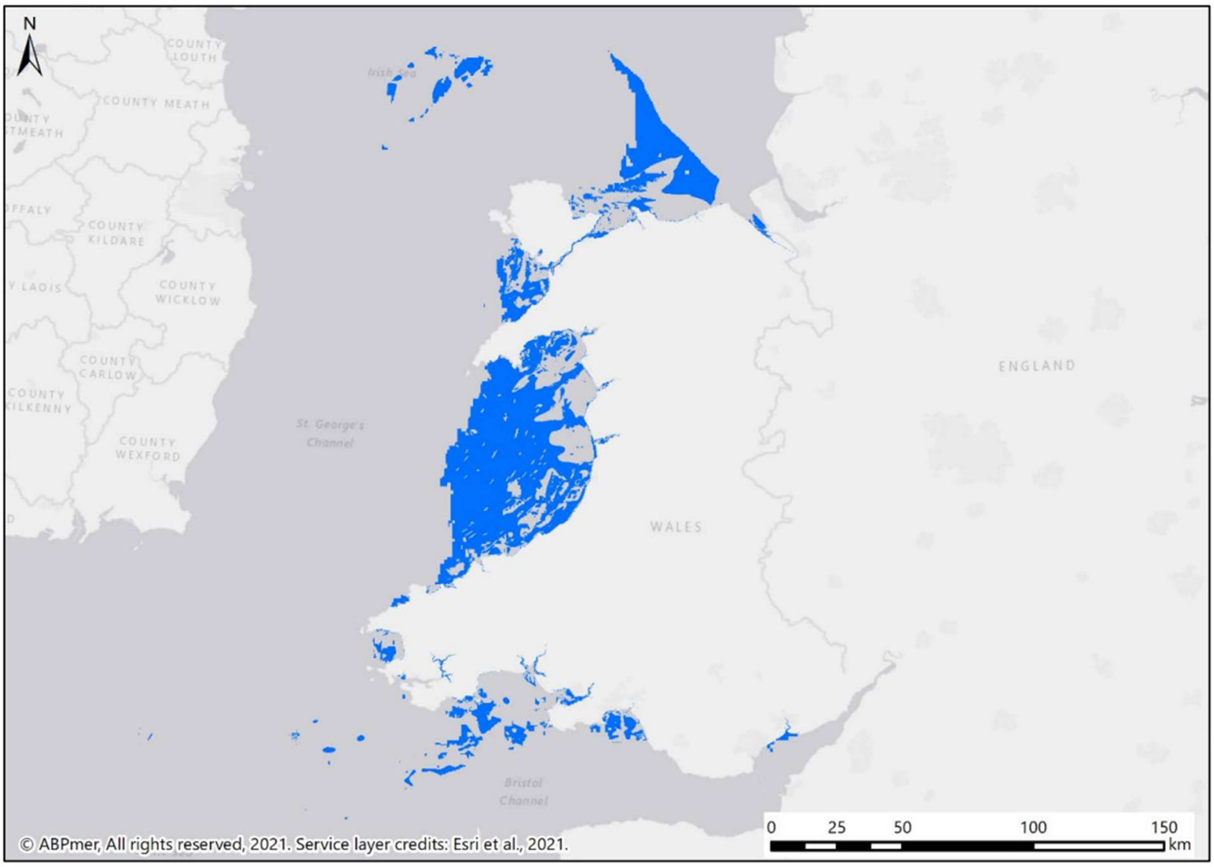

Figure 7. *Native oyster opportunity areas (within the model extent of 0 to 80 m depth) from Armstrong et al., 2021. Contains Natural Resources Wales information © Natural Resources Wales and Database Right. All rights Reserved.*

Similarly to the EA in England, the spatial opportunity datalayers are being refined by NRW working with The Crown Estate and ABPmer. The Welsh Marine Enhancement Mapping Project is focused on improving knowledge and tools to identify where marine habitats and species in Wales can be restored or enhanced, ultimately strengthening the resilience of marine and coastal ecosystems. The project combines updated scientific evidence, practical mapping tools, and key actor input to guide effective marine habitat restoration in Wales.

It has three main components:

1. Evidence Review and Workbook Update

The project is updating an existing evidence workbook (first developed in 2016) that compiles information on important marine habitats and species in Wales. This update will include the latest data, research, and key actor input, creating a comprehensive resource on their condition, pressures, and opportunities for enhancement.

2. Opportunity Mapping Methodology and Pilots

A key aim is to develop a clear, step-by-step method for mapping which considers opportunities and hard and soft constraints that could affect restoration success. This approach will be tested on two habitats—seagrass and native oyster—by refining existing maps into more practical "feasible opportunity" maps that consider environmental, social, and logistical factors.

3. Key Actor Engagement and Workshops

The project places strong emphasis on collaboration, involving expert consultations and workshops. This includes an initial workshop (February 2026) and two later, habitat-focused workshops (May 2026) to review and improve mapping outputs.

Incorporating environmental, social, and practical constraints and opportunities is important to better identify locations where marine habitat restoration is possible and most likely to succeed. This information also informs National Action Plans being developed and delivered in Wales for native oyster, seagrass and saltmarsh (NSAP, 2024; West *et al.,* In prep.)

Under the *Connecting Conwy* project, habitat suitability mapping will be conducted for the native oyster for North Wales. The habitat mapping will utilise a range of fine-scale oceanographic, geologic and biophysical data and overlay historic distributions of *O.edulis* (Hayden-Hughes *et al.,* 2023, Thurstan *et al.,* 2024) summarised in Table 7. Assessing suitability based on the environmental conditions and historic presence of oysters will help identify feasible sites for recovery initiatives. This work will contribute to a field campaign to ground-truth habitat suitability, identifying knowledge gaps and data limitations when modelling is applied to localised fine-scale regions.

Table 7. *Summary of factors and parameters applied to determine O. edulis habitat suitability*

Factors/ Predictors	**Suitable range**	**Notes**	**Reference**
Bathymetry/ Water depth (m)	>-79 m and <-1m	Water depth below mean sea level	Ward *et al.,* 2023
Bed shear stress	Maximum sea bed shear stress (N/m^2)	It was not clear if the bed shear stress values given in the literature were means or maxima. Ranges suggest means. Furthermore, it was	Ward *et al.,* 2023; Neill 2024

		unclear if they reflected currents only or currents and waves combined. Here, bed shear stress is calculated as the combination of both current- and wave-induced bed shear stress (max BSS currents plus mean BSS winter waves).	
Current velocity (m/s)	>0.125 m/s and <0.8 m/s	Here, depth averaged currents were used. Sea bed currents will be ~50% - 80% of the depth averaged currents.	Ward *et al.,* 2023
Sediment composition	Sand and mud with gravel and/or shell present; shells; gravel; rock and boulders	Classified according to Folk16 scale	Smeaton *et al.,* (2021)
Total suspended matter	< 60 mg/l		EMODnet Total Suspended Matter
Salinity (psu)	>25 psu		Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast, Copernicus Marine Service
Winter temperature (°C)	>3 °C	Here, annual minimum monthly mean temperatures were used. Ideal winter temperature has been noted as >7°C, but literature suggests survival possible at very low temperatures.	Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast, Copernicus Marine Service
Oxygen	>3.5 mg/l	Annual mean of monthly mean oxygen concentrations used	Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast, Copernicus Marine Service
Chlorophyll	>1.68 µg/l		North West Shelf Region, Bio-Geo-Chemical, L4, monthly means and interpolated daily observation, Copernicus Marine Service (Lee *et al.,* 2002; Gons *et al.,* 2005; Novoa *et al.,* 2017; O'Reilly *et al.,* 2019; Alvera-

			Azcárate *et al.,* 2021; Lavigne *et al.,* 2021)
Historic occurrence data	NA		Hayden-Hughes *et al.,* (2023); Thurstan *et al.,* (2024)

5.2 Blue mussel, *Mytilus edulis*

5.2.1 Habitat Overview and Ecological Importance

The blue mussel, *Mytilus edulis*, is a suspension feeding bivalve commonly found on the mid intertidal shore down to the shallow sublittoral (Connor *et al.,* 2004). The native distribution of the species is throughout the North Atlantic (Bayer *et al.,* 2017) though it has spread globally now being found in the pacific as far south as Australia (Zbawicka *et al.,* 2022). Blue mussel beds, formed by individuals binding together via byssal threads into complex, multidimensional structures, are recognised as distinct biotopes (JNCC, 2022; Mainwaring *et al.,* 2014). Table 8 summarises the abiotic and biotic habitat suitability characteristics at different life stages for *M. edulis.*

The blue mussel is an important commercial fishing species in the UK and Ireland producing approximately 15,500 tonnes, valuing more than USD$14 million in 2023 (FAO, 2024a; 2024b). Until recently, mussel fisheries within the Menai Strait contributed to 35% of the total production in the UK (Ellis *et al.,* 2015). Unfortunately, the mussel fisheries in the Menai Strait have reported a decrease in landings since 2008 (Ellis *et al.,* 2015). The majority of mussels harvested from the Menai Strait were previously exported to the Europe prior to the withdrawal of the UK from the EU. Since Brexit, mussel production has collapsed with only one mussel dredging vessel operating on the Menai Strait.

Blue mussel beds play a foundational role in coastal ecosystems by stabilising the seabed and providing a secure habitat for a variety of marine life (Meadows *et al.,* 1998; Saier, 2002). These beds support diverse organisms such as small crustaceans, molluscs, worms, and juvenile fish (Koivisto and Westerbom, 2010; Saier, 2002). They also attract larger predators such as sea birds, and adult fish, contributing to productive food webs (van der Zee *et al.,* 2012; Stounberget *et al.,* 2023). Beyond their ecological importance, blue mussels provide valuable ecosystem services. Their filter-feeding improves water quality, helping to reduce harmful algal blooms and supporting recreational water use (Schories *et al.,* 2006). Mussel beds also reduce sediment erosion and attenuate wave energy, aiding shoreline stabilisation and natural coastal protection (Baxter *et al.,* 2022; Donker *et al.,* 2013). Additionally, they contribute to carbon sequestration, playing a role in climate regulation (Jansen and van de Bogaart, 2020).

Blue mussel beds are now faced with a myriad of threats, stemming from human activities, climate change, and natural biological challenges. Blue mussel beds are classified as a threatened and declining species (OSPAR Commission, 2008). Mussel beds in Wales, and across the UK, have reduced in size (Saurel *et al.,* 2004) and since 1990 there has been a reduction in spat availability (Gazeau *et al.,* 2013). Direct human impacts such as overfishing, coastal development, and water pollution have degraded mussel habitats and reduced population stability (Sampaio *et al.,* 2022). At the same time, climate change is intensifying these pressures through rising sea temperatures, with recurrent heat waves reducing thermal tolerance, lower salinities decreasing growth rates sea level rise that alters intertidal habitats and submerges suitable settlement areas, and more frequent and severe storms that can destroy well established mussel beds (Fujii and Raffaelli, 2008; Landes *et al.,* 2015; Seuront *et al.,* 2019; Jaatinen *et al.,* 2021; de Smit *et al.,* 2024). Compounding these issues are natural stressors like disease, inconsistent spatfall and the spread of invasive species increasing competition for resources (Mainwaring *et al.,* 2014; Rolin *et al.,* 2016; Joyce *et al.,* 2019). Together, these threats are reducing the resilience of blue mussel populations, leaving them increasingly vulnerable.

There are invasive species that could potentially impact the mussel fisheries in the Menai Strait. The Bangor Mussel Production Association and the Countryside Council for Wales (CCW); now Natural Resources Wales (NRW), agreed upon and signed the Code of Good Practice to reduce the risk of invasive, non-native species to the Menai Strait (Wilson and Smith, 2008; MacAlister, 2010). The Code of Good Practice identified eight key invasive non-native species (INNS); the American jack knife clam (*Ensis leei*), carpet sea squirt (*Didemnum vexillum*), Chinese mitten crab (*Eriocheir sinensis*), slipper limpet (*Crepidula fornicata*), orange-tipped sea squirt (*Corella eumyota*), veined rapa whelk (*Rapana venosa*), chain tunicate (*Botrylloides violaceus*) and wakame (*Undaria pinnatifida*). The invasive non-native species can directly impact mussel abundance, or form dense colonies or mats, that can indirectly affect the growth and survival of mussels (Thieltges, 2005; Switzer *et al.,* 2011). The impacts of nuisance and invasive species on mussel productivity are a major concern for the industry (Enright, 1993; Dürr and Watson 2010).

Restoration is an important approach for the continued survival of blue mussels, given the numerous threats they face. In the Wadden Sea, an experimental restoration trial involved transplanting blue mussels onto stable substrates to facilitate adhesion. However, within seven months, all transplanted mussel beds had disappeared, likely due to challenging hydrodynamic conditions (de Paoli *et al.,* 2015). This trial underscored the difficulties associated with mussel transplantation for restoration. More recently, restoration efforts have focused on using specially engineered structures designed to support the self-facilitating feedback loops inherent in mussel life cycles, thereby enhancing transplantation success (Schotanus *et al.,* 2020). This approach resulted in higher mussel densities within the structures and improved restoration outcomes by reducing both dislodgement and predation. These findings highlight the importance of innovative techniques tailored to the species for effective restoration.

***Table 8**. Abiotic and biotic habitat suitability characteristics, relevance to various life-history processes and their ranges for the Blue mussel (Mytilus edulis).*

ABIOTIC & BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT	RANGE	REFERENCE
Sediment composition				X	Larvae settle on filamentous substrate. Coarse hard natural and artificial substrates, mixed, muddy gravel, muddy sand, sandy mud	Bayne 1976; Seed 1969; Tyler-Walters, 2008a.
Suspended sediment (mg/l)		X			100	Purchon, 1937; Moore, 1977; De Vooys, 1987; Widdows *et al.,* 1998
Temperature winter, Tmin (˚C)	X				-10	Williams, 1970; Seed & Suchanek, 1992
Temperature summer, Tmax (˚C)	X				29	Read & Cumming, 1967; Almada-Villa *et al.,* 1982
Oxygen conditions (mg/l)	X				> 2	Zwaan de & Mathieu, 1992
Salinity (PSU or ppt)	X				18-40	Newell 1979; Holt *et al.,* 1998
Food concentration (chl*a* in µg/l)		X			Growth > 0.5	Dolmer, 2000; Pascoe *et al.,* 2009
Larval retention				X	Larvae dispersal potential >25km Duration of larval stage 1-6 months	Demmer *et al.,* 2022a; Bayne, 1965; Bayne, 1976; Lane *et al.,* 1985; Strathmann, 1987
Predation	X				High numbers of predators can decimate a population	Holt *et al.,* 1998
Competition		X			Competition for food and space can reduce growth and reproduction	(Seed & Suchanek, 1992)
Water Depth	X				Intertidal – 5m	(Tyler-Walters, 2008a)

Current velocity (m/s)				X	<0.5- 16	(Young 1985)
Bed shear stress (tau N/m^2)	X				Max < 4.6	(Widdows *et al.,* 2009)
Sea Bed mobility (cm/day)	X				< 2	(Widdows *et al.,* 2002; Last *et al.,* 2011)

5.2.2 Habitat suitability and modelling review

There is currently no comprehensive UK-wide habitat suitability model for *Mytilus edulis*. While some spatial mapping has been undertaken, it remains fragmented and is typically limited to specific sites or regions rather than covering the UK. For example, work in Scotland has mapped historical distributions and inferred habitat extent, identifying 124 mussel bed locations through spatial reconstruction (Heard *et al.,* 2025).

Natural Resources Wales (NRW) has a published spatial dataset of the known location and extent of habitats which are of "Principal Importance" for the purpose of maintain and enhancing biodiversity in relation to Wales under the Environment (Wales) Act (2016) including blue mussel beds and are regarded as "threatened or declining" under OSPAR in Wales (Figure 8). Similarly, the Joint Nature Conservation Committee (JNCC) provides biotope records that indicate where environmental conditions support blue mussel beds in certain estuaries and mudflats, including the Dee Estuary and Severn Estuary in Wales. Although these are not explicit habitat suitability maps, they provide biotope-based indications of suitability. Biotopes which explicitly include *M. edulis* beds are 'littoral mussel beds on sediments', 'sublittoral mussel beds', and 'mussel beds on mixed substrata or sand'. These maps are derived from survey-based datasets, including Marine Recorder, UKSeaMap, and EMODnet, rather than purely predictive modelling approaches.

Figure 8*. Map of extent and location of blue mussel beds (dark blue areas) classed of "Principal Importance" under the Environment (Wales) Act (2016), Section 7 and are regarded as "threatened or declining" under OSPAR in Wales. Contains Natural Resources Wales information © Natural Resources Wales and Database Right. All rights Reserved. Contains Ordnance Survey Data. Ordnance Survey Licence number AC0000849444. Crown Copyright and Database Right. Derived in part from data provided under licence by the British Geological Survey © NERC.*

Predictive modelling efforts do exist but are often limited in scope. For instance, modelling in the southern North Sea has estimated the distribution potential of *M. edulis* in relation to offshore turbine structures and hydrodynamic conditions (Slavík *et al.,* 2019). Although such work is typically embedded within broader ecosystem studies rather than presented as standalone UK-wide suitability maps. Similarly, spatial modelling has been applied at smaller scales for aquaculture planning (Hughes and King, 2023; Mascorda-Cabre *et al.,* 2024; Corrochano-Fraile *et al.,* 2024) or within specific water bodies (Stechele *et al.,* 2022). Other studies have modelled how *M. edulis* distribution may shift under climate change scenarios (Fly *et al.,* 2015).

Internationally, habitat suitability modelling has been completed for the blue mussel in the Dutch Wadden Sea reporting that suitability is strongly influenced by salinity and hydrodynamics (van der Meer *et al.,* 2025). Environmental predictor variables used in the study included:

- Annual average salinity at high tide (PSU)
- Salinity variability
- Water depth (m)
- Maximum current velocity (m/s)
- Orbital velocity of waves (m/s)
- Maximum bottom shear stress due to currents (Pa)
- Sediment silt content (%)
- Sediment median grain size (μm)
- VMS fishing intensity data
- Dredging shipping lanes

A knowledge gap was highlighted in van der Meer *et al.,* 2025 stating improved understanding of temporal dynamics and settlement limitations could significantly enhance future conservation and management decisions.

Restoration initiatives in other countries also provide useful lessons learnt. In Denmark, active mussel restoration is being led by the Centre for Marine Restoration, which aims to ensure that marine nature restoration of boulder reefs, eelgrass meadows, biogenic reefs and costal realignment in Denmark takes place on a knowledge-based basis, so that investments are optimal. DTU Aqua plays a central role in collecting and synthesising data to guide restoration efforts of biogenic reefs. In Denmark, biogenic reefs include not only blue mussels (*M. edulis*) but also horse mussel (*Modiolus modiolus*), European flat oyster (*Ostrea edulis*). Guidance documents have been developed outlining criteria for site selection, establishment, and monitoring of mussel beds, which could be adapted for use in other regions such as Wales if suitable data are available (Nielson *et al.,* 2024a; 2024b). Table 9 describes the criteria for selecting suitable areas for the establishment of blue mussel beds (Nielson *et al.,* 2024a). These initiatives also offer insights into permitting and management of the restored sites, particularly given the commercial importance of *M. edulis* (Nielsen *et al.,* 2024b). Comparable restoration work on other mussel species, such as the *Perna canaliculus* in New Zealand, further contributes to the global evidence base (Benjamin *et al.,* 2023).

__Table 9.__ Necessary or possible criteria for selecting suitable areas for the establishment of mussel beds. The criteria are divided into four categories: Environmental conditions, project logistics, marine planning and practical establishment considerations. Source Nielsen et al., 2024a.

ENVIRONMENTAL CONDITIONS		YES	NO	NO INFORMATION
ESSENTIAL	*Water depth* : Minimum water depth of 3 m.			
	Suitable substratum : Site specific but generally sites with low content of organic matter indicated by a LOI-value <10%.			
	Salinity : Salinity of the area is between 10-35 PSU.			
	Oxygen depletion : The site is not affected by oxygen depletion (>4 mg O_2/L).			
DESIRABLE	*Resuspension frequency* : Areas with low resupension frequency			
	Resident blue mussel beds : Blue mussel beds are observed in the adjacent areas.			
	Phytoplankton concentration : Is chlorophyll-a concentrations >0.5 µg/L during the growth season (Mar-Oct).			
	Predators : Avoid areas with observations or knowledge of predators e.g. mussel eating birds and starfish.			
PROJECT LOGISTIC				
ESSENTIAL	*Agreement of use of the area* : Is collaboration and agreement with stakeholders in the area needed?			
	Licencing : Is licence(s) needed for e.g. seed collection and bed establishment? Are relevant authorities identified?			
DESIRABLE	*Protection status after establishment* : Is the site protected from physical disturbance?			
	Outreach and stakeholder engagement : Is stakeholder engagement and outreach activities required or relevant?			
	Supporting infrastructure: Is sufficient supporting infrastructure available?			
	Historical distribution : Maps or anecdotal knowledge of mussel beds in the area			
MARINE SPATIAL PLANNING				
ESSENTIAL	*Marine protected areas (MAP)* : Site located within a MPA?			
	Areas for resource utilisation or repositories : Is the site outside areas appointed to resource utilisation or repositories?			
	Infrastructure facilities : Selected site is located >100 m away from infrastructure facilities			
	Existing habitats: Site is at a sufficient distance to existing habitats e.g. eelgrass beds, stone reefs or ares with gravel			
DESIRABLE	*Outlet from rivers and streams* : Need for extra sampling of sediment and/or salinity?			
	Shipping and sailing routs : Sufficient distance to shipping or sailing routs (e.g. contact authorities).			
	Recreational activities : Use of the site by recreational activities?			
PRACTICAL ESTABLISHEMNT CONSIDERATION				
ESSENTIAL	*Seed collection:* what type of seeds (from the seabed or from the water colum), should be used?			
	Transfer of mussel seeds between areas : Are the seeds collected within the same area (or alternativley from nearby areas), as the area of establishment?			
	Areas required for seed collection and establishment of beds: Has an assessment been made of the areas needed for seed collection and establishment of bed(s)?			
	Method of deployment: What type of vessel should be used, and what method, for example, manual or mechanical?			
DESIRABLE	*Design of the mussel beds:* Have considerations been made regarding: i) density of the mussels ii) distance between beds iii) one or multiple deployments iv) time of year for establishment of beds			

Within the UK, the Blue Mussel Restoration Network was established by the Tees Rivers Trust in 2023 in response to reported declines in blue mussel populations. This network brings together academics, conservationists, regulators, and NGOs who are interested in the blue mussel. The Tees River Trust is seeking permission to deploy

"Tree Reefs", circular, biodegradable reef structures made from discarded fruit trees, onto the seabed to encourage mussel recovery along the northeast England coast.

In North Wales, local nature partnerships and environmental NGOs are also beginning to explore opportunities for blue mussel regeneration, reflecting growing interest in restoring this ecologically and economically important species.

5.3 Seagrass: Eelgrass, *Zostera marina* and Dwarf eelgrass, *Zostera noltii*

5.3.1 Habitat Overview and Ecological Importance

Seagrasses are marine flowering plants, characterised by their long above-ground, leaf-like blades and extensive below-ground rhizome network. Around the UK coastline, there are two commonly distributed species: common eelgrass, *Zostera marina*, and dwarf eelgrass, *Zostera noltii*. Common eelgrass is predominantly found in subtidal waters up to depths of 13m, growing to lengths of 2m, although a shorter and thinner morphotype, sometimes referred to as *Zostera angustifolia*, exists in intertidal pools (Davidson and Hughes, 1998; Tyler-Walters, 2008b). The genetic distinctness of *Z. marina* and *Z. angustifolia* is disputed (d'Avack *et al.,* 2014). Dwarf eelgrass is a smaller plant that colonises intertidal mudflats, estuaries, and shallow lagoons (Tyler-Walters, 2005). Above ground, it's ribbon-shaped leaves can grow to lengths of 22cm, which seasonally die-back leaving an extensive rhizome network below the sediment (Vermaat & Verhagen, 1996). The current extent of seagrass meadows in the UK is estimated to be 8,500ha with 722 ha in Wales, 172 ha in north Wales (Green *et al.,* 2021). Included are summaries of the abiotic and biotic parameters at different life stages of *Z. marina* (Table 10) and *Z. noltii* (Table 11).

Seagrass meadows play a critical role in sediment stabilisation and carbon cycling. Their thin blades capture and draw down suspended sediment, which is then held and stabilised by an extensive rhizome network. This process promotes sediment accretion, reduces coastal erosion and improves water quality (de los Santos *et al.,* 2020; Paul, 2018). Through this sediment stabilisation, organic carbon from trapped particles and seagrass detritus is buried and stored beneath the meadow. Simultaneously, seagrass absorbs dissolved CO_2 from the surrounding water during photosynthesis, converting it into organic biomass through carbon fixation. Together, these processes enable seagrass meadows to act as efficient carbon sinks, contributing significantly to climate change mitigation (Greiner *et al.,* 2013). Furthermore, seagrass meadows attenuate wave energy, providing natural coastal defence by dissipating wave forces before they reach the shore (Reidenbach and Thomas, 2018).

As an intertidal ecosystem, seagrass meadows function as essential habitats during both submerged and exposed tidal phases. These meadows support dense and diverse benthic invertebrate communities (Boström and Bonsdorff, 1997). When inundated, seagrass meadows act as nursery grounds offering shelter and foraging opportunities for the early life stages of ecologically and commercially important fish species, such as pollack (Pollachius pollachius) and plaice (Pleuronectes platessa) (Bertelli and Unsworth, 2014). During periods of tidal exposure, the seagrass blades and associated invertebrate fauna serve as vital foraging grounds for wading and migratory bird species, including brent geese (Branta bernicla) (Ganter, 2000; Unsworth and Butterworth 2021).

Globally seagrass extent is declining at a rate of 7% a year (Waycott *et al.,* 2009). Since the 1980s the UK has lost at least 39% of healthy seagrass meadows and estimates show that up 92% may have been lost over a longer period (Green *et al.,* 2021). The largest threats to seagrass have been identified as direct human impacts (Grech *et al.,* 2012). Some of the leading anthropogenic causes of decline are costal development, land reclamation reducing suitable habitat for meadows, and bottom-towed fishing gear tearing through meadows as with boat mooring and anchoring. Seagrasses are also susceptible to climate change induced pressures. A major issue for seagrasses is sea level rise causing increased wave action in previously sheltered areas and water depths changing, reducing suitable habitat that meadows can grow in (Tang and Hadibarata, 2022). Additionally, warming waters are likely to lead to changes in distribution of seagrass species with some species being pushed polewards and others expanding their range (Valle e al., 2014). Water pollution and increased storm severity also pose a threat, poor water quality reduces the light available for photosynthesis and extreme storms can cause physical disturbances to the meadows (Carlson *et al.,* 2010).

The long-term dynamics of *Zostera marina* and *Z. noltii* and both species resilience and survival to these increasing pressures is unknown. However, interventions, whether active restoration or relieving pressures, can help species recover. In recent years, *Z. noltii* extent has increased in parts of Wales, including Angle Bay within the Pembrokeshire Marine SAC, in response to management of waterways (Bertelli *et al.,* 2018; Moore *et al.,* 2021; Jackson-Bué *et al.,* 2025d; West *et al.,* 2025).

Seagrass restoration has been trialled in the UK since the 1970s (Randwell *et al.,* 1974). The two main approaches are reseeding and transplanting. Seagrass restoration projects in have historically had low levels of success. Environmental conditions have been deemed the major determining factor in success and researchers have advised practitioners to only perform restoration initiatives in suitable environmental conditions or risk complete project failure (Unsworth *et al.,* 2018). Habitat suitability models have been useful tools in determining which areas to focus restoration efforts (Bertelli *et al.,* 2022). Recently England's largest restoration project has come to an end after reseeding 8 hectares in the Solent through various techniques (Natural England, 2024). Project seagrass runs UKs largest restoration initiative across England, Wales, and Scotland. In Dale Bay, South West Wales over 1 million seeds have been planted across 2 hectares and the team are now exploring new mechanistic approaches to upscale the process (Unsworth *et al.,* 2022).

Table 10. *Biotic and abiotic parameters of eelgrass, Zostera marina. Source: Seagrass Restoration Handbook (Gamble et al., 2021). The data provided in this table are sourced from studies across the range of Zostera marina but provide a useful starting point. Further information is required from the UK and Ireland to fully understand the environmental parameters for successful seagrass restoration at the local and regional scales.*

ABIOTIC AND BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT
Sediment composition	*Zostera marina* can found in a range of sediment EUNIS habitats: • A2.2/5.2 intertidal/subtidal sand, 63µm–0.5mm. > 80% sand (MarLIN). • A2.3/5.3 intertidal/ subtidal mud, < 63µm (silt/ clay fraction). > 80% mud (MarLIN). • A2.4/5.4 intertidal/ subtidal mixed sediments. • 15–90% of silt, particles < 63µm (Zhou *et al.,* 2016).	Optimum suggested to be 60–80% (% of silt, particles < 63µm) (Zhou *et al.,* 2016). Nitrogen rich sediment can increase vegetative growth while phosphorus enriched sediment can slightly improve vegetative growth (Qin *et al.,* 2021).	Optimum likely to be the same as growth. Nitrogen enriched sediment can help stimulate sexual reproduction (Qin *et al.,* 2021).	The optimum seed germination sediment is a 2:1 mixture of sand: silt (Wang *et al.,* 2016). Anoxic sediment environment increases the likelihood of germination; this is created by finer sediment, as it is less porous (Cumming *et al.,* 2017).
Light (% surface irradiance SI mol photons m^{-2} s^{-1})	Minimum light requirements estimated to be 18% surface irradiance (SI); or > 20µmol photons m−2 s−1 (Lee *et al.,* 2007; Erftemeijer and Lewis 2006;	Between 12% and 37% of SI to survive in the long-term; maximum growth rates of 100– 150µmol photons µm−2s−1 (Dennison and	Likely the same as growth, although data unavailable.	Research on light and dark exposure has shown no consistent effect on seed germination (Moore *et al.,* 1993).

	Bertelli and Unsworth 2018). Underwater min values of 10.3±7.4µmol photons m−2 s-1 have been observed in Irish seagrass beds (Beca-Carretero *et al.,* 2019).	Alberte 1985; Olesen and Sand-Jensen 1993; Lee *et al.,* 2007; Erftemeijer and Lewis 2006; Bertelli and Unsworth 2018).		
Temperature winter, Tmin (°C)	0°C (Zimmerman *et al.,* 2017)	13 and 24°C (Lee *et al.,* 2007). Stop growing at 20°C and start to die off at 25°C (Reusch *et al.,* 2005).	Optimum suggested to be between 15 and 20°C (Nejrup and Pedersen 2008).	Optimum seedling development for North Sea populations of *Zostera marina* occurs at 10°C (Hootsmans *et al.,* 1987). In populations at the southern tip of their global distribution, germination occurs at 18–20°C (McMillan 1983), which suggests that this species can tolerate and adapt to a wide range of temperatures.
Temperature summer, Tmax (°C)	30°C-45°C (Zimmerman *et al.,* 2017)	13 and 24°C (Lee *et al.,* 2007). Stop growing at 20°C and start to die off at 25°C (Reusch *et al.,* 2005).	Optimum suggested to be between 15 and 20°C (Nejrup and Pedersen 2008).	Seedlings are unable to survive at higher temperatures (Abe *et al.,* 2008) and if summer temperatures exceed 28°C for long periods of time, the species may not recover from seasonal

				die-offs (Shields *et al.,* 2018). Maximum seed germination was recorded in freshwater at 15°C (Xu *et al.,* 2016).
Predation	Green shore crabs Carcinus maenas have been responsible for a large proportion of seagrass seed depletion as they can consume 10 seagrass seeds a day, with each seed being consumed whole (Infantes *et al.,* 2016).	Several different species of herbivorous water birds feed on *Zostera marina* blades: Eurasian coot *Fulica atra*, Swans *Cygnus* spp., Dabbling ducks *Anas* spp. and Brent Geese *Branta bernicula* in intertidal or shallow water areas (Ganter 2000).	*Same as left*	*Same as left*
Water depth (m)	Exists in intertidal (up to 4m above chart datum) (Tyler-Walters, 2008b), and as low as 10m in clear waters. Will depend upon conditions such as light availability and wave action. Depth limits in turbid estuarine conditions can be < 2m. Around the UK, maximal depth limit is typically between 0.5 and 4m (Davison and Hughes 1998;	Optimum growth will depend on other conditions, predominantly light availability, but studies suggest most extensive seagrass growth/densities at ~ 2m (Hannam *et al.,* 2015; Xu *et al.,* 2020) or at 1–6m (Zhou *et al.,* 2016).	Some studies show higher numbers of flowering shoots in deeper seagrass bed areas (~ 5.5m, Kim *et al.,* 2014) or at deeper seagrass bed edges (Olesen *et al.,* 2017).	Seedling recruitment can occur throughout the whole seagrass bed range, although it may be higher at deeper seagrass bed edges where there is a higher proportion of bare area and lower competition (Kim *et al.,* 2014; Olesen *et al.,* 2017).

	Jackson *et al.,* 2013).			
Salinity (PSU or ppt)	10–39 PSU (Davison and Hughes 1998).	15–20 PSU for optimal growth (Zhou *et al.,* 2016).	Data unavailable.	Optimum salinity for *Zostera marina* seedling establishment and colonisation appears to be above 20 PSU in natural beds (Xu *et al.,* 2016). Rapid near-complete germination found at full salinity (30 ppt) under anaerobic conditions, or at lower salinity (15 ppt) under aerobic conditions (Probert and Brenchley 1999).
Oxygen conditions (mg l^{-1})	Not reported in the literature. Believed to be tolerant of low oxygen in the short-term but long periods of low oxygen may have an impact (MarLIN).	Data unavailable.	Data unavailable.	Moore *et al.,* (1993) found that *Zostera marina* seeds needed to be buried in at least 0.5cm of anoxic sediment to germinate. Anaerobic conditions are preferred for higher germination rates but dependent on salinity (see above, Probert and Brenchley 1999).
Current velocity (ms^{-1})	5–180 cm.s-1 (Koch 2001).	Optimal velocity ≤ 0.5ms-1 (Tyler-Walters 2008b; Zhou *et al.,* 2016).	Data unavailable.	Data unavailable.

Table 11*. Biotic and abiotic parameters of dwarf eelgrass, Zostera noltii.*

ABIOTIC AND BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT
Sediment composition	*Zostera noltii* can found in a range of sediment EUNIS habitats: • A2.2 intertidal sand, 63µm–0.5mm. > 80% sand (MarLIN). • A2.3 intertidal mud, < 63µm (silt/ clay fraction). > 80% mud (MarLIN). • A2.4 intertidal mixed sediments. Patch survival can be decreased by high sulphide, >1000 µmol L^{-1} and ammonia levels, >2000 µmol L^{-1},(Govers *et al.,* 2014) Preferred substrates are muddy sand and sandy mud with a finer texture (Pratt, 2016; Paling *et al.,* 2025)	The addition of organic matter to sediments can lead to a decrease or inhibition of *Noltii* growth, but this can be alleviated with high light conditions (Olivé, 2009)	Silt/clay and organic matter content are linked to flowering effort, with lower grain size and higher organic matter increasing flowering effort (Guerrero-Meseguer *et al.,* 2021),	Likely the same as reproduction, but data unavailable.
Light (% surface irradiance SI mol photons m^{-2} s^{-1})	Minimum light requirement is 2% SI, or for growth was 0.8 mol photons m-	Rhizome branching was only observed at 42% SI (Peralta, 2002).	Likely the same as growth, although data is unavailable.	Severe shading, 1-7% SI lead to reduced clonal expansion and shoot

	$^{2}day^{-1}$. (Peralta, 2002)			recruitment (Peralta, 2002)
Temperature winter, Tmin (°C)	Survival in a range of temperatures between 7°C and 23°C (Pratt, 2016). 5°C (Paling *et al.,* 2025, Massa *et al.,* 2009) Intertidal populations of *Noltii* might be damaged by frost leading to mortality (den Hartog, 1987; Covey & Hocking, 1987)	Temperatures increase from 7°C to 25°C are linked to an increase in *Noltii* growth (Cognat *et al.,* 2018) Optimum suggested to be between 10°C and 15°C (Pratt, 2016).	Likely to be the same as growth and recruitment but data unavailable.	Optimum suggested to be between 10°C and 15°C (Pratt, 2016).
Temperature summer, Tmax (°C)	30°C-37°C (Paling *et al.,* 2025)	Close to 100% mortality found at or above 39°C, 90% at 37°C and 95% at 35°C (Massa *et al.,* 2008). Optimum suggested to be between 10°C and 15°C (Pratt, 2016).	Flowering continued when seawater temperatures dropped to 14 °C in November (Ankel *et al.,* 2021)	Recruitment was highest at 30°C, combined with a psu of 10 (Hootsmans *et al.,* 1987). Optimum suggested to be between 10°C and 15°C (Pratt, 2016).
Predation	Wildfowl can lead to reductions in *Zostera noltii* biomass of greater than 60%, however this can recover the next year and it has been suggested that the disturbance is necessary (Tubbs & Tubbs, 1983;	Overwintering wildfowl heavily graze *Zostera noltii* beds, these include Brent geese *Branta bernicla,* wigeon *Anas penelope,* mute and whooper swans *Cygnus olor* and *Cygnus cygnus.*(MarLIN., 2026) Seed and seedling density have been	As described left	Recruitment can be hampered by *Hediste diversicolor* as it consumes leaves and sees and pulls them into its burrow and reducing the survival of seedlings (Huges *et al.,* 2000)

	Nacken & Reise, 2000)	found to be higher in experimental pits designed to mimic greese feeding pits, which corroborated other research (Nacken & Reise., 2000; Zipperle *et al.,* 2010)		
Water depth (m)	Exists in the intertidal, but where water cover is permanent it is usually out competed by *Zostera marina* (Paling *et al.,* 2025). *Noltii* is found at a range of depths from 0-10 m and adapts to these different depths with its growing behaviour (Pratt, 2016)	Likely the same as survival, but data unavailable.	Likely the same as survival, but data unavailable.	Likely the same as survival, but data unavailable.
Salinity (PSU or ppt)	*Z. noltii* can survive in a range of salinities from 5% to 30% (Pratt, 2016)/. Full (30-40 psu), variable (18-40 psu) (Paling *et al.,* 2025).	A range of 22-23 psu was found to be optimal for *Z. noltii* growth (Suykerbuyk *et al.,* 2018).	Data unavailable.	Optimum salinity for germination is 1.0% which can be driven by freshwater run off (Hootsmans et al, 1987; Pratt, 2016) Low salinity (1-10psu) increased germination in *Zostera noltii* with no germinations occurring above 20 psu (Paling *et al.,* 2025).

Oxygen conditions (mg l^{-1})	Not reported in the literature but it is believed to be tolerant of low oxygen in the short-term nut prolonged deoxygenation may have an effect (MarLIN 2026).	Data unavailable.	Data unavailable.	Data unavailable.
Current velocity (ms^{-1})	*Z. noltii* occurs in sheltered or extremely sheltered locations with low current velocity (Paling *et al.,* 2025)	Increased current velocity (0.01, 0.10 and 0.35 m s^{-1}) leads to the increase of growth rates and elongation of leaves (Peralta *et al.,* 2006)	Data unavailable.	Increase current velocities lead (0.01, 0.1 and 0.35 ms^{-1} to increased recruitment rates (Peralta *et al.,* 2006)

5.3.2 Habitat suitability and modelling review

In 2020, the Joint Nature Conservation Committee (JNCC) published a Habitat Suitability Model for *Zostera marina* beds in the UK displayed in Figure 9 (Castle *et al.,* 2022). The dataset was produced using an ensemble modelling approach, utilising the random forest algorithm to predict habitat suitability of eelgrass beds across the UK. Outputs of the model described the probability of habitat occurrence as a percentage, with the overall resolution of the dataset being 300 x 300m, and the standard deviation of the predictive values of the habitat suitability model. This describes the variability of the habitat suitability models derived from fifty iterations using a random forests approach to indicate the level of confidence.

The response variables (presence/absence data) were extracted from:

- OSPAR T&D Habitats Database (2018)
- Marine Recorder Database (2019)
- Annex I Reefs Database (2018)

The predictor variables (environmental datasets) used within the model include:

- Depth to seabed
- Slope of seabed
- PAR at the Seabed
- Kinetic energy at the seabed due to currents
- Kinetic energy at the seabed due to waves

- Seabed Substrate
- Mean of annual minima temperature at the seabed (over 30-year period)
- Absolute minimum of seasonal salinity

A literature review was conducted to inform the model of the environmental characteristics known to influence the distribution of all habitats, using the following sources:

- Strong J.A. (2016)
- The Marine Life Information Network (MarLIN) [see D'Avack *et al.,* 2019]
- OSPAR Background document [see Tullrot 2009]
- Brown (2015)
- Bekkby *et al.,* (2008)

The key predictor variables affecting the distribution of eelgrass beds were, in order of importance: water depth, amount of sunlight (PAR) at the seabed minimum salinity, mean of annual minima temperature at the seabed and wave energy at the seabed. Other studies (Bekkby *et al.,* 2008; other studies) included wave exposure as a predictor variable. However, this study has shown that it does not have a high importance value for the model. This may be due to the resolution of the dataset used being insufficient to capture small-scale variability.

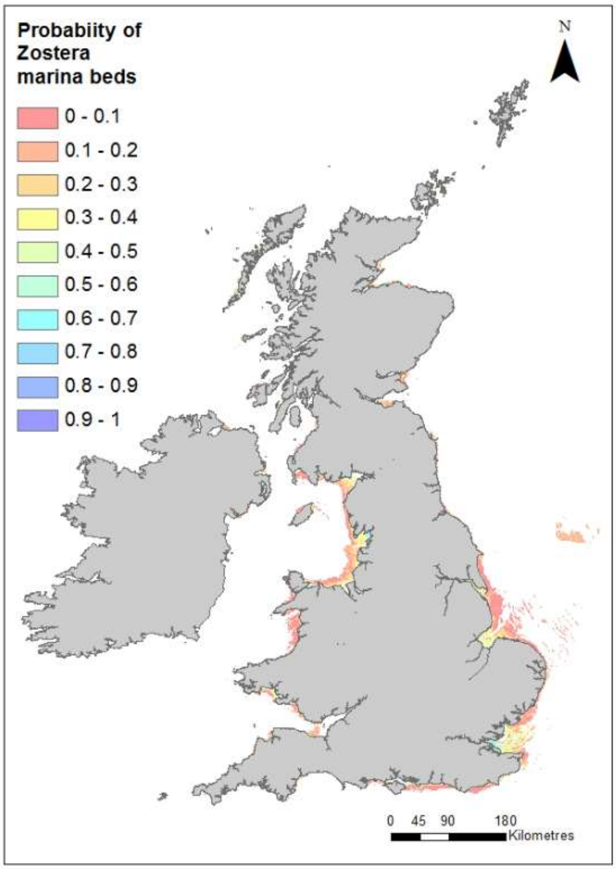

Figure 9. *Output from Environment Agency's habitat suitability model for Zostera marina beds in the UK presenting the probability of eelgrass habitat occurrence as a percentage (Castle et al., 2022).*

Bertelli *et al.,* (2022) published a supplementary data table of the extracted factors of interest (geographical area and scale of study, taxa, species, approach to modelling, model method (algorithm, selection and validation) and environmental variables) used in previous habitat suitability model studies to determine the distribution of marine macrophytes.

In Wales, Natural Resources Wales (NRW) published in 2026 a spatial assessment identifying potential opportunities for the restoration or creation of common eelgrass (*Zostera marina*) habitats in Welsh waters (Figure 10). This map includes a combination of mapped areas of *Z. marina*, habitat suitability model outputs and locations of suitable mapped habitat along the coast where the modelled outputs are absent. The data includes outputs from the JNCC *Z. marina* habitat suitability model (Castle *et al.,* 2022), Bertelli *et al.,* (2022) Zostera habitat suitability, extracted data from JNCC's UKASH and NRW's section 7/OSPAR data.

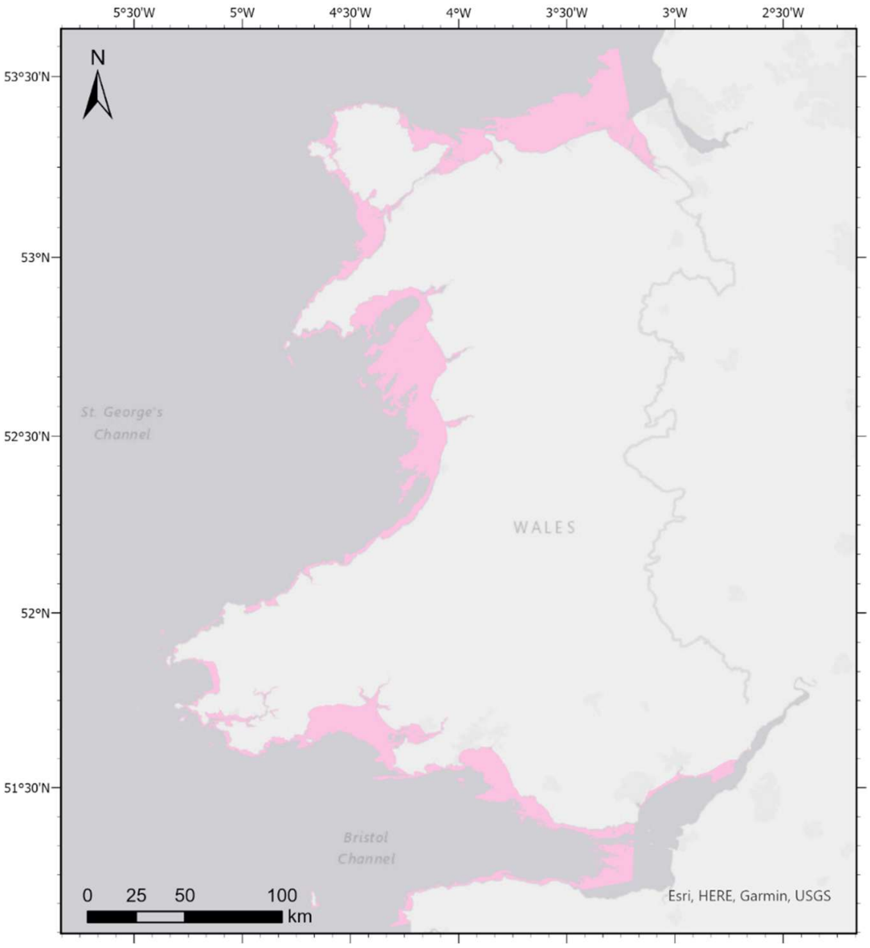

Figure 10. *Map showing areas that are suitable for the predominantly subtidal seagrass species Zostera marina and is needed to provide advice on where Natural Resources Wales would potentially support restoration or creation projects for Zostera marina. Contains Natural Resources Wales information © Natural Resources Wales and Database Right. All rights Reserved. Contains data based on JNCC USKASH, © JNCC and other data providers as set out in their data inventory. Source DataMap Wales.*

In the current study localised habitat suitability mapping will be conducted for *Z. noltii* for North Wales. The habitat mapping will utilise a range of fine-scale oceanographic, geologic and biophysical data to predict potential sites for recovery initiatives (Table 12). This work will contribute to a field campaign to ground-truth habitat suitability, identifying knowledge gaps and data limitations when modelling is applied to localised fine-scale regions.

Table 12. *Data sources used to derive environmental variables for Z. noltii habitat suitability model across the North Wales study area.*

Environmental variable	Resolution	Data source
Water depth	50 m	Model grid from Ward *et al.,* (2023)
Bed shear stress	50 m	Ward *et al.,* 2023
Salinity (annual minimum)	~1/36°	Copernicus Marine Service North-West Shelf Ocean Physics Analysis and Forecast product
Temperature (annual minimum)	~1/36°	Copernicus Marine Service North-West Shelf Ocean Physics Analysis and Forecast product
Total suspended matter (mean)	0.00314°	EMODnet Physics database
Sediment type	Mean resolution 270 m (110 m close to the shore)	Smeaton *et al.,* (2021, Supplementary Materials)
Average water flow speed at seabed	50 m	Ward *et al.,* 2023
Slope	50 m	Ward *et al.,* (2023) model grid
Distance from closest shore	30 m	Ward *et al.,* (2023) model grid

5.4 Saltmarsh

5.4.1 Habitat Overview and Ecological Importance

Saltmarsh habitats are dynamic transitional coastal fringes, connecting terrestrial and coastal waters on sheltered temperate coastlines (Ladd, 2021). Saltmarshes are characterised by intertidal areas of fine sediments that have been stabilised by dense vegetation (Boorman, 2003). This vegetation only occurs on the saltmarsh flats while a system of muddy creeks runs in between them (Reed *et al.,* 2009). The vegetated flats are frequently inundated by tides, creating harsh conditions for plant growth as the result of the high salinity and anoxic content in the soil. However, as halophytes saltmarsh plants are well adapted to these hostile conditions (Pennings and Bertness, 2001). Saltmarsh vegetation displays strong spatial zonation largely driven by frequency of inundation (Bockelmann et al, 2002), see below Figure 11 and Table 13. The Welsh coastline is estimated to have 6,950 ha of saltmarsh (EA, 2011).

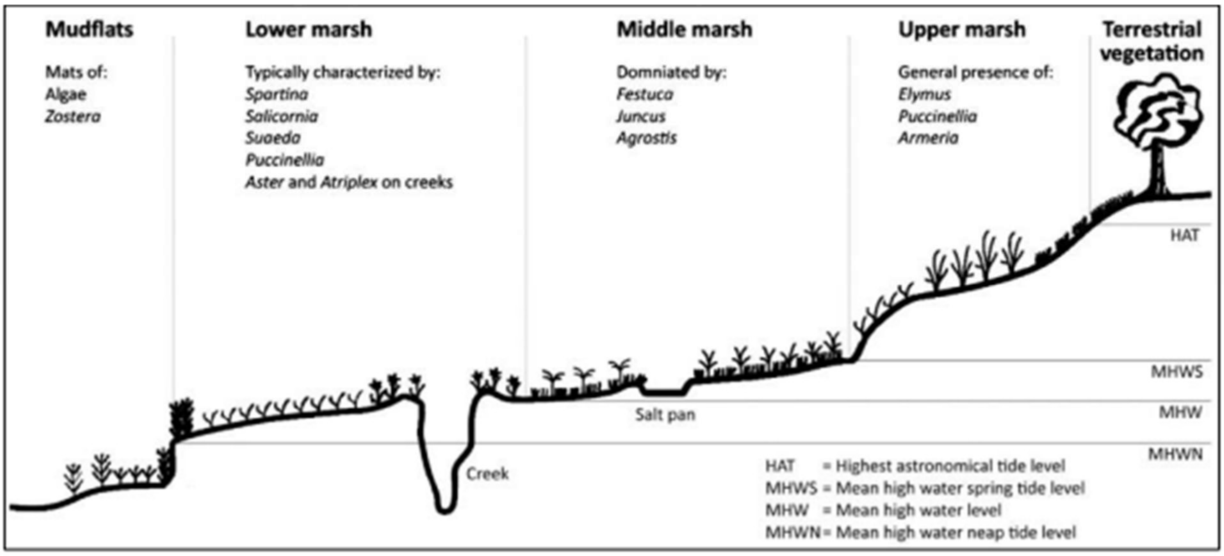

Figure 11. *Generalised division of intertidal habitats based on elevation in relation to tidal height (from Davis et al., 2018)*

Table 13. *Habitats associated with number of tidal inundations per year (Source: MMO, 2019 using information from Toft et al., 1995; Leggett et al., 2004)*

Inundations Per Year	Habitat
More than 450	Mudflat
450 to 360 (maximum continuous exposure: 9 days; minimum daily daylight submergence of 1-2 hours)	Pioneer marsh
Less than 360 (typical 300) (minimum continuous exposure: 10 days; maximum daily daylight submergence of 1 hour)	Low, mid and upper saltmarsh

Saltmarsh habitats perform an array of ecosystem services such as carbon sequestration, sea defence, water filtration and nutrient cycling summarised in Figure 12 (McKinley *et al.,* 2018; Hudson *et al.,* 2021). The estimated value of flood mitigation by salt marsh across England and Wales is £2.05 billion (Office for National Statistics, 2022). Additionally, these habitats are known be nursery grounds for juvenile fish providing structural shelter and an abundance of food (Boesch and Turner, 1984). Saltmarshes are also crucial habitats as feeding and overwintering grounds for a range of bird species, such as the common redshank (Tringa tetanus) (Hughes, 2004).

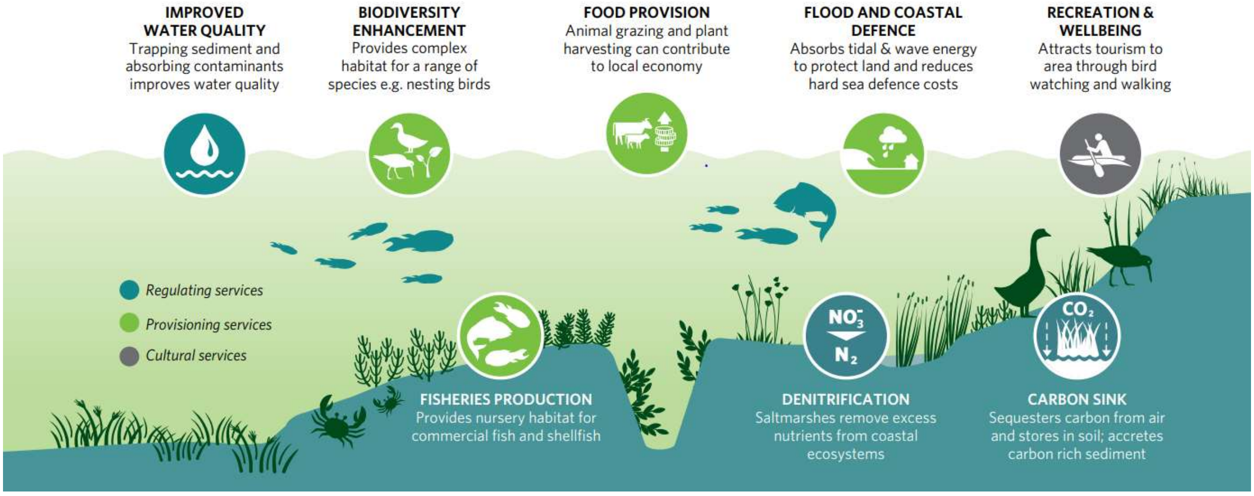

Figure 12. *Ecosystem services provided by saltmarshes. (Source: Hudson et al., 2021)*

Historically, saltmarshes were seen as wastelands, since the 19th century saltmarshes have been subjected to land reclamation for agricultural purposes, coastal developments, or waste management (Doody, 2008). Saltmarsh habitats face other pressures such as sea level rise and coastal squeeze from human developments (Burden *et al.,* 2020; Cole Ekberg *et al.,* 2017). This combination of factors has resulted in major losses seeing England lose 85% of saltmarsh habitat since the 1860’s, with the UK projected to lose a further 5,262 ha by 2060 (Hudson *et al.,* 2021; EA, 2023). Another pressure saltmarshes face is grazing from livestock (McKinley *et al.,* 2022). In Wales there is a niche market for saltmarsh grazed lamb and beef, these products often sell for markedly higher prices (Gedan *et al.,* 2009). Grazing can shape the composition of the vegetation and therefore can change how the habitat functions for other animals such as birds and fish (Laffaille *et al.,* 2000; Bakker *et al.,* 2020). However, when appropriately managed grazing can have minimal impacts on plant diversity (Chen *et al.,* 2020). Table 14 summarises the abiotic and biotic characteristics of saltmarsh habitat.

Saltmarsh restoration is now being prioritised as a nature-based solution for flooding defence, coastal protection, and carbon storage thanks to the recognition of its ecosystem services (Figure 6) (Doody, 2013; Burgess *et al.,* 2021 Hudson *et al.,* 2021). The estimated value of flood mitigation by saltmarsh across England and Wales is £2.05 billion (ONS 2022). A wide variety of techniques have been developed to restore and conserve saltmarsh, from large scale projects restoring over 200 ha (Scott *et al.,* 2016), to smaller initiatives that aim to conserve existing threatened saltmarshes (Billah, 2022). One of the most common methods is managed realignment, in which sea defences are deliberately breached or removed to allow the land to be inundated by the tide and overtime develop into saltmarsh (Esteves, 2014). Alternatively, man-made structures can be installed to retain sediment around existing saltmarshes. This approach reduces erosion and promotes sediment accretion in adjacent areas, facilitating the expansion of saltmarsh vegetation. Examples include the use of coir rolls or BESE matting along marsh edges and channels, as well as large fenced-in areas known as sedimentation fields (Hudson, *et al.,* 2021). Another technique, intertidal recharge, involves redistributing dredged sediment from port or channel maintenance to enhance and protect saltmarsh environments by using the material as a tidal barrier or to raise land elevations prior to managed realignment (Hudson, *et al.,* 2021). A combination of all techniques is often used to maximise restoration success and accelerate ecological succession (Billah, 2022).

Table 14. *Abiotic and biotic characteristics that characterised saltmarsh ecosystems*

ABIOTIC & BIOTIC CHARACTERISTIC	HABITAT CONDITIONS
Grazing pressure	Grazing by livestock and wild herbivores affects vegetation height, species composition, soil compaction, and habitat structure in saltmarshes. In Wales, 66% of saltmarshes are grazed, mostly at light to moderate levels (<0.7 LSU ha^{-1} yr^{-1}), with only around 5% intensively grazed (McKinley *et al.,* 2022).
Sediment composition	Low survival chances given by poor supply of fine sediment. High survival for areas that receive high levels of fine sediments (Hudson *et al.,* 2021). Sediment grain size reflects hydrodynamic energy and tidal regime. Macrotidal saltmarshes are generally sand dominated, while microtidal marshes are richer in silt and clay. Within estuaries, particle size varies with sediment source: fine alluvial silt and clay dominate near the estuary head, mixed clay and silt in the mid-estuary, and marine sands near the estuary mouth (Magar, 2016; Ladd, 2021).
Suspended sediment (mg/l)	Although not of immediate importance, it is relevant in terms of the long-term supply of sediment necessary for saltmarsh surface accretion (Boorman, 2003).
Temperature (˚C)	The coastal location of salt marshes moderates thermal extremes. Tidal inundation alters soil temperatures, with warmer autumn tides enhancing vegetation growth and colder spring tides delaying soil warming, collectively causing a slight offset in seasonal temperature shifts (Boorman, 2003).
Oxygen conditions (mg/l)	Plant roots play a key role in alleviating soil anoxia. Oxygen transported through roots can diffuse into surrounding soils, benefiting neighbouring plants (Bertness, 1991; Ladd, 2021). Shading from vegetation reduces evaporation and salt accumulation, further improving growth. As marshes mature, plant development is enhanced through root water uptake, oxygen diffusion via plant tissues, and the formation of permanently aerated soil layers, which collectively reduce phytotoxicity and support a more oxygenated substrate (Dacey and Howes, 1984; Pezeshki, 2001; Ladd, 2021).
Salinity (PSU or ppt)	Saltmarshes are regularly inundated by sea water and hence they are characterised by high salinity. Salinity impacts on germination and root elongation of seeds (Katembe *et al.,* 1998; Boorman, 2003). Variation in salinity strongly affects the structure and succession of plant and animal communities in saltmarsh ecosystems (Hudson *et al.,* 2021).
Wave exposure	Saltmarshes occupy intertidal zones that act as a critical interface between land and sea, generally occurring in sheltered to extremely sheltered

	environments such as estuaries and tidal inlets (Townend *et al.,* 2010; JNCC, 2022).
Plant colonisation	Vegetation grows on sandy and muddy sediment compositions with a composition of coarser material (Parry and Hendy, 2022).
Elevation	Higher elevation saltmarshes experience less frequent inundation, allowing less salt-tolerant plants to outcompete halophytes and eventually transition to terrestrial species at the landward edge (Allen, 2000; Ladd, 2021). Plant zonation is strongly influenced by soil salinity and anoxia, both of which decrease with increasing marsh elevation (Ladd, 2021).
Water velocity	The velocity will differ based on the tidal range and the geomorphology of the area; on average the rates of flow are within a range of 0.5-2 meters per second. Higher velocity in the marsh creek, while lower velocity in the marsh surface cause by plant colonisation that allows the suspended sediments to settle **(**Boorman, 2003).
Bed shear stress (tau N/m^2)	Wave action and tidal asymmetry influence foreshore morphology, with bed shear stress regulating sediment redistribution and maintaining equilibrium along the intertidal zone (Ladd, 2021).
Tidal inundation	Saltmarshes are structured into distinct zones according to tidal inundation frequency, salinity, and tidal scouring. The pioneer zone is flooded most frequently, followed by the low, mid, and upper marsh zones, which experience progressively fewer inundations. Mudflats are submerged over 450 times per year, pioneer marshes between 360–450 times, and higher marsh zones typically around 300 times annually (Armstrong *et al.,* 2021).

5.4.2 Habitat suitability and modelling review

Habitat suitability models for saltmarsh restoration usually rely on factors such as land elevation and proximity to tidal waters. The Marine Management Organisation (MMO, 2019) developed a screening tool to help identify realistic sites for managed realignment and regulated tidal exchange. This tool assesses Flood Zone 3 areas alongside several other factors, including distance from the sea, land designations, and existing infrastructure, among others. A summary of the datalayers created can be found in Table 15. A similar tool has been developed for Scotland (Smeaton *et al.,* 2022).

Table 15. *Summary of data layers created for the saltmarsh and mudflat restoration in the MMO project no.1135 (Source: MMO et al., 2019)*

Habitat	Datalayer name	Description	Main creator	Main input datalayers
Mudflats and saltmarshes	Potential habitat creation sites within the current floodplain	Currently defended floodplain areas which could be suitable for managed realignment and / or RTE. Polygon data.	ABPmer	Environment Agency tidal and tidal/fluvial floodplain
	Potential beneficial use (mud) – stretches which may benefit	Stretches of SSSI-designated low-energy shorelines thought to be eroding due to coastal squeeze. Line data.	ABPmer	Natural England SSSI Units, OS Mean High water Springs (MHWS) line
	Potential beneficial use (mud) - potential material sources (maintenance dredge disposal sites)	Review of disposal site data, highlighting those from which materials suitable for mudflat or saltmarsh restoration could potentially be diverted. Point data.	ABPmer	Cefas disposal sites

To address the need for Welsh data, Natural Resources Wales (NRW) commissioned a study (Armstrong *et al.,* 2021). Like the MMO tool, it also uses Flood Zone 3 data, but it combines this only with Shoreline Management Plan (SMP) data. As a result, the Welsh dataset identifies broad areas of potential opportunity (Figure 13), but not all of them are realistically suitable for managed realignment. It is intended as a starting point for further investigation rather than a definitive site list.

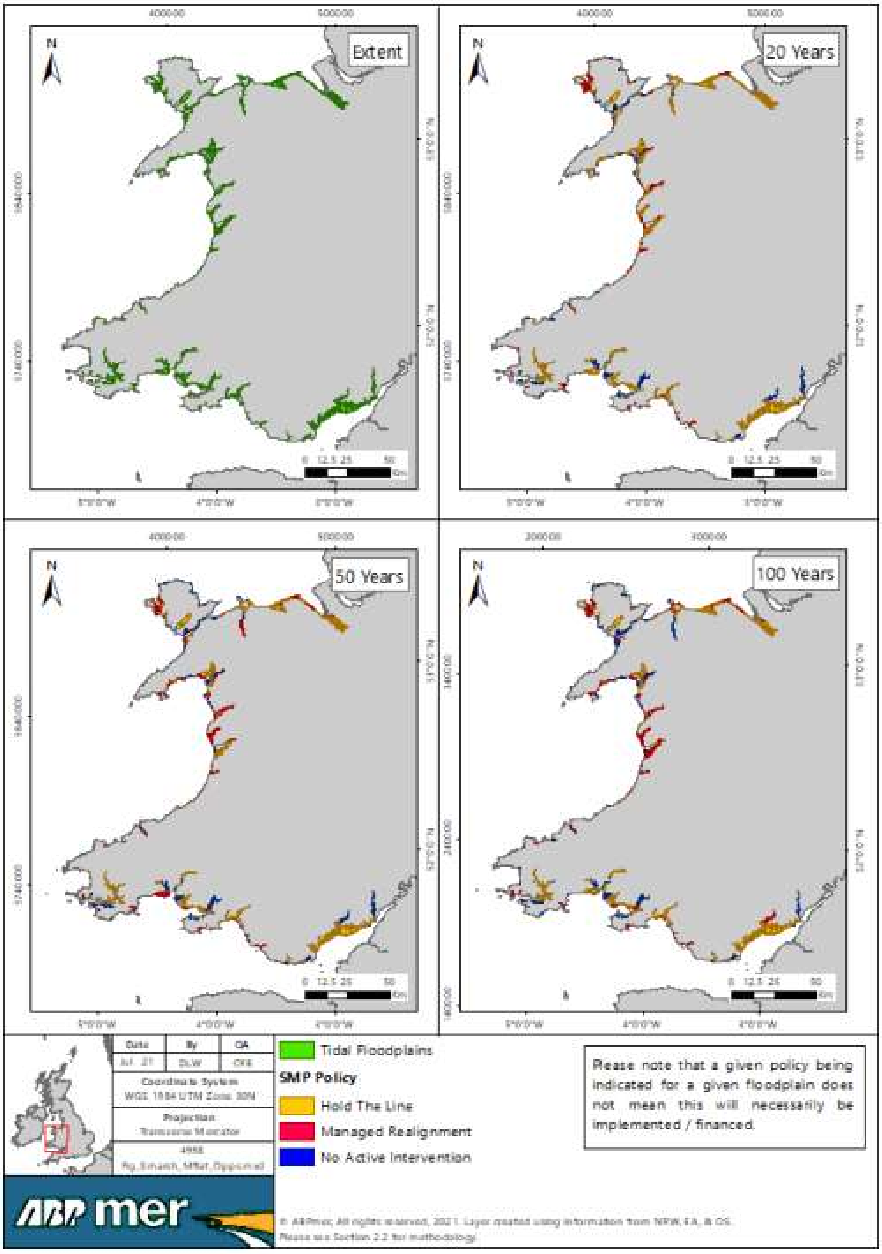

Figure 13. *Welsh tidal floodplains and applicable SMP policies. Areas marked in red are potential opportunities for managed realignment. (Source: Armstrong et al., 2021)*

Across the United Kingdom, approximately 75 managed realignment projects have been implemented, of which only four are located in Wales (Armstrong *et al.,* 2021). One example is Cwm Ivy, situated in Loughor estuary, South Wales, where the sea wall was breached in 2014 following an assessment that maintenance was no longer sustainable (Dale *et al.,* 2021). The site has since been allowed to revert naturally to its original intertidal condition and is managed as a nature reserve by the National Trust. Cwm Ivy now supports a range of saltmarsh vegetation providing habitat for wading bird species such as egrets as well as commercially important fish species such as European bass.

The most comprehensive spatial data on Welsh saltmarshes comes from the Saltmarsh Extents dataset published by Natural Resources Wales in 2017 (Figure 14). This dataset maps the full extent of saltmarsh habitats along the Welsh coastline using high-resolution aerial imagery with a pixel size of 10 centimetres. It identifies both the seaward and landward limits of saltmarsh vegetation, where the seaward limit is defined by vegetation cover dropping below five percent, and the landward limit is where saltmarsh plants give way to more terrestrial vegetation, often at the base of seawalls or embankments. The mapping covers areas in both coastal and transitional waters and provides a consistent national baseline for monitoring change. Although comprehensive, the 2017 dataset represents a single point in time, and updated surveys or monitoring would be needed to understand recent changes caused by erosion, sea level rise, or restoration work.

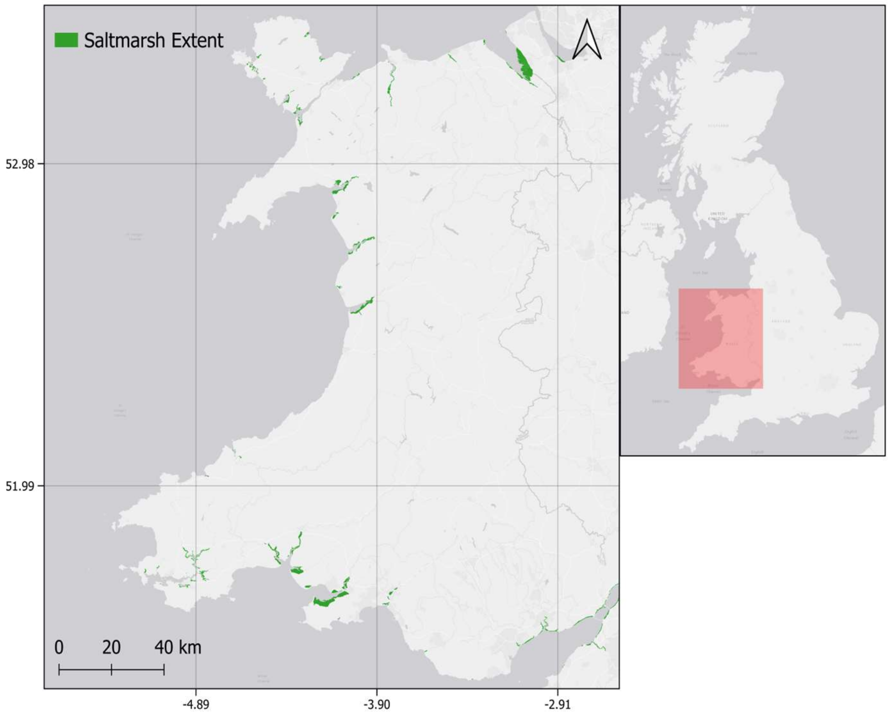

Figure 14. *Saltmarsh extent in Wales (NRW, 2017). The extent is shown in green, derived from data obtained from DataMap Wales, an open-source geoportal maintained by Natural Resources Wales. Contains Natural Resources Wales information © Natural Resources Wales and database right.*

6. Conclusion

This desk-based study represents the first consolidated review of evidence relating to the extent, condition, distribution, and environmental context of key marine habitats across the Menai Strait and Conwy Bay SAC. Drawing together historical records, ecological monitoring data, seabed and hydrodynamic datasets, assessments of environmental pressure, and previous habitat suitability approaches, it establishes a coherent and comprehensive evidence base from which the next phase of technical and restorative work can confidently proceed.

The main purpose of this review was to assemble the information required to inform updated habitat suitability modelling for ***Ostrea edulis*** and ***Zostera marina***. By integrating data on bathymetry, sediment character, hydrodynamics, water quality, historic habitat presence, and species ecology, the report provides the most complete and consistent technical foundation currently available for the region. The variety of methodologies and datasets collated here — along with their noted limitations, temporal coverage, and spatial resolution — will help guide the development of standardised mapping approaches and support national efforts to build a shared evidence database.

6.1 Evidence Gaps and Recommendations

The process of compiling this evidence base has improved understanding of where knowledge is strong and where critical gaps remain. These gaps have implications for the design and performance of subsequent habitat suitability modelling (HSM) and are summarised here to inform both modellers and future survey design.

From a modelling perspective, several constraints are likely to influence the quality and scope of the HSM outputs. A key limitation is the spatial resolution of predictor variables. Existing national-scale models (e.g. JNCC *Zostera marina* HSM) typically operate at a 300 m resolution, which is insufficient to capture fine-scale environmental variability. This is particularly problematic in hydrodynamically complex environments such as the Menai Strait and shallow areas, where small-scale changes in physical conditions can strongly influence habitat presence.

To address this, Bangor University, through the *Connecting Conwy* Project, is developing high-resolution HSMs for *Ostrea edulis* and *Zostera noltii* along the North Wales coastline. These models aim to provide spatially explicit insights to support restoration and management efforts. They will integrate fine-scale oceanographic, geological, and biophysical datasets, alongside historic distribution records of *O. edulis*, to compensate for the current lack of contemporary presence data and to help ground-truth model outputs.

However, model outputs will remain constrained by data availability. Key environmental variables—such as dissolved inorganic nutrients, sedimentation rates, turbidity, and wave exposure—are often unavailable at sufficiently fine spatial scales, particularly for shallow infralittoral and intertidal environments. In such cases, proxy datasets or remotely sensed data may be required, introducing additional uncertainty.

As a result, model performance metrics should be interpreted with caution, especially where presence and absence data are limited. Outputs should be considered as indicative of potential habitat suitability rather than definitive site assessments. Ground-truthing, supported by targeted field surveys, will be essential to validate predictions within the project area.

It is also important to recognise that HSMs cannot incorporate all factors relevant to restoration feasibility. Model outputs do not provide the full picture as data is not available for all variables. Inputs such as human-induced pressures (ie. disturbance), natural pressures (ie. predation) and biological interactions (ie. reproduction) cannot be considered. Outputs should therefore be used as a guide to identify potentially suitable areas for the recovery of *Ostrea edulis* and *Zostera noltii*, and supplemented with additional assessments. These should include environmental factors (e.g. water quality), biological processes (e.g. larval behaviour and recruitment), and practical constraints (e.g. existing licensed activities, land ownership, and protected site designations). Integrating environmental, social, and operational considerations will improve identification of locations where restoration is both feasible and likely to succeed.

Specific evidence gaps identified through this review include:

- Limited availability and spatial extent of high-resolution environmental data, constraining both model coverage and predictive accuracy
- Reliance on proxy or remotely sensed data (if possible) where direct measurements are unavailable
- Sparse presence and absence records for key species
- Insufficient data coverage extending to the high tide line, limiting intertidal habitat modelling

Across all habitats, water quality remains a critical cross-cutting issue. Particularly the failure of five of the seven Water Framework Directive (WFD) waterbodies overlapping the SAC for chemicals. A constraint on the feasibility of restoration and requires continued monitoring and improvement upstream.

In addition, the role of invasive non-native species represents a significant knowledge gap. In particular *Crepidula fornicata*, which has been expanding in the Menai Strait since approximately 2019, may interact with and potentially hinder restoration of target species, but these dynamics are not yet well understood.

Finally, there is a need to ensure that model outputs are robust to future environmental change. Incorporating climate change projections into modelling frameworks remains an important area for further development.

The findings of this desk study should be read alongside forthcoming habitat suitability model technical reports produced by Bangor University as part of the *Connecting Conwy Project*.

6.2 Implications Seascape-Scale Recovery

The evidence collated in this desk-based study sits within growing scientific and policy consensus that successful and impactful coastal recovery depends on restoring ecological connectivity across a mosaic of habitats, rather than isolated interventions. Preston *et al.,* (2025) provide a framework for considering ecological connectivity in marine systems and demonstrate through expert consensus and structured review that ecosystem functioning and the full delivery of ecosystem services require a healthy mosaic of connected coastal habitats.

The functional linkages between oyster reefs, seagrass meadows, saltmarshes, blue mussel beds, and intertidal mudflats — operating through larval dispersal, sediment stabilisation, nutrient exchange, wave attenuation, and blue carbon accumulation — mean that the value of any restored habitat is amplified when it exists as part of a connected seascape. The paper explains, ecological connectivity allows organisms, nutrients, sediment, and energy to move between different marine habitats, driving crucial ecosystem services from carbon storage to water filtration, coastal protection, and fishery productivity. The potential for coastal habitats to deliver these ecosystem services is amplified when they co-exist as one connected habitat mosaic, forming the temperate coastal seascape.

The inter-habitat connectivity matrices published in Preston *et al.,* (2025), covering mudflat, seagrass, saltmarsh, oyster, and macroalgae interactions (Figures 15 and 16), provide an important reference framework for the *Connecting Conwy* context. They illustrate both the strength of existing evidence for inter-habitat connectivity and the knowledge gaps that remain, particularly for temperate European seascapes. The accompanying seascape connectivity infographic illustrates how restored and reconnected habitats collectively underpin climate mitigation, biodiversity recovery, and human wellbeing — outcomes that are directly relevant to the conservation objectives of the Menai Strait and Conwy Bay SAC and to the ambitions of the #NNF3 Connecting Conwy project.

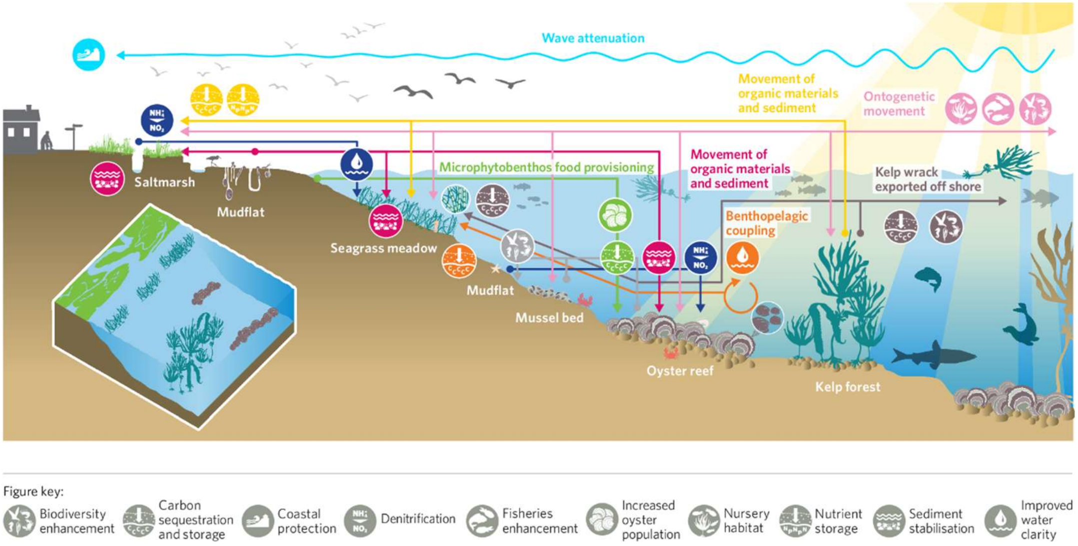

Figure 15. *Illustration of the role of connectivity in modulating ecosystem service delivery across the coastal seascape.*

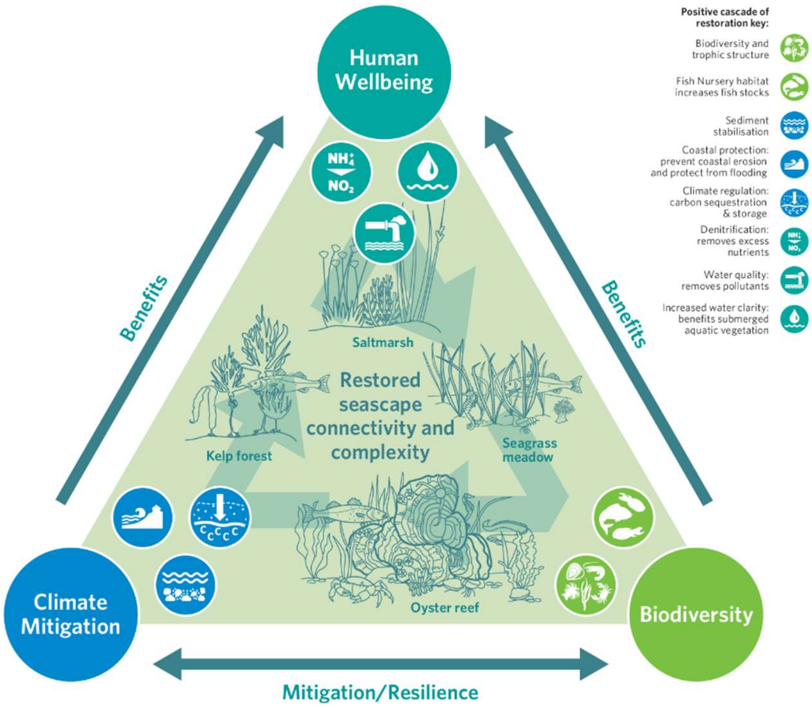

Figure 16. *Conceptual diagram of how ecosystem service delivery from a restored and connected seascape underpins the interrelationships between climate mitigation, biodiversity and human wellbeing.*

Looking ahead, the Menai Strait and Conwy Bay region holds potential for a coordinated, partnership, multi-habitat, seascape-scale restoration. Remnant habitat patches persist, regional research capacity is strong, and policy frameworks at Welsh, UK, and international levels are increasingly aligned with this ambition (zu Ermgassen *et al.,* 2025). Targeted and coordinated restoration activities, such as native oyster reef recovery, seagrass restoration, saltmarsh expansion and improvements to mussel bed condition, could collectively rebuild ecological connectivity that has been lost through degradation. These activities would need to be sequenced carefully, evidence-based, informed by the outcomes of habitat suitability modelling and ground-truthing surveys, and developed in close partnership with local communities, fishers, aquaculture operators, and statutory bodies.

6.3 Next Steps

This desk study provides the foundation for the next phase of evidence gathering and planning for the #NNF3 Connecting Conwy project. The following steps will ensure that the evidence base is strengthened, validated, and co-produced with local partners.

Local actor mapping*:* An actor mapping exercise will be conducted identifying priority local actors early engagement, and invitees to the initial workshop. This includes fishers, local authorities, NGOs, aquaculture operators, and community groups whose knowledge, interests, and cooperation are essential to the long-term success of any restoration programme.

Preliminary workshop: A workshop with key local actors will be convened to establish shared priorities, understand perceived challenges and opportunities for collaboration, and cross-reference local knowledge with the evidence gaps identified through this desk study. This co-production approach will help ensure that subsequent technical work reflects the needs and values of those who live and work within the seascape.

One-to-one knowledge exchange meetings: Targeted meetings with statutory bodies, research teams, marine users, and coastal communities will continue, gathering site-specific information on feasibility, logistics, local sensitivities, and historical context that cannot be captured through desk-based methods alone.

Feeding evidence into modelling and future planning: All relevant datasets and findings from this desk study will be supplied to the modelling team at Bangor University. The combined outputs — desk study review, HSM reports, local actor engagement insights, and ground-truthing survey data — will together inform the development of a long-term seascape restoration plan for Conwy Bay and the Menai Strait, alongside habitat-specific feasibility assessments, prioritisation of restoration opportunity areas, and future funding proposals and project development.

Together, these steps will move the project from evidence review towards planning for future action and building the collaborative, science-led, community-supported foundations needed to deliver meaningful seascape-scale marine habitat recovery in one of Wales's most important coastal environments.

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8. Supporting/Supplementary information

8.1 Appendix 1

List of species and habitats protected at each Marine Protected Area within and near the project region of Conwy Bay and Menai Strait (adapted from source: Welsh Government, 2018).

SAC	Marine/Coastal Feature
Y Fenai a Bae Conwy / Menai Strait and Conwy Bay	Reefs Mudflats and sandflats not covered by seawater at low tide Large shallow inlets and bays Submerged or partially submerged sea caves
Great Orme's Head / Pen y Gogarth	European dry heaths Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia)* (* important orchid sites) Vegetated sea cliffs of the Atlantic and Baltic Coasts
North Anglesey Marine / Gogledd Môn Forol	Harbour porpoise *Phocoena phocoena*
Dee Estuary / Aber Dyfrdwy (Wales/England)	Mudflats and sandflats not covered by seawater at low tide Salicornia and other annuals colonizing mud and sand **Atlantic salt meadows** (*Glauco-Puccinellietalia maritimae*) Estuaries Annual vegetation of drift lines Vegetated sea cliffs of the Atlantic and Baltic Coasts Embryonic shifting dunes "Shifting dunes along the shoreline with *Ammophila arenaria* (""white dunes"")" "Fixed coastal dunes with herbaceous vegetation (""grey dunes"")" * Priority feature Humid dune slacks Sea lamprey River lamprey Petalwort

Glannau Mon: Cors heli / Anglesey Coast: Saltmarsh	Salicornia and other annuals colonizing mud and sand **Atlantic salt meadows** (*Glauco-Puccinellietalia maritimae*) Estuaries Mudflats and sandflats not covered by seawater at low tide
Y Twyni o Abermenai i Aberffraw / Abermenai to Aberffraw Dunes	Embryonic shifting dunes "Shifting dunes along the shoreline with *Ammophila arenaria* (""white dunes"")" "Fixed coastal dunes with herbaceous vegetation (""grey dunes"")" *Priority feature Dunes with *Salix repens* ssp. argentea (*Salicion arenariae*) Humid dune slacks Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation Petalwort *Petalophyllum ralfsii* Shore dock *Rumex rupestris*
Glan-traeth	Great crested newt *Triturus cristatus*
Afon Gwyrfai a Llyn Cwellyn	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the Isoëto-Nanojuncetea Water courses of plain to montane levels with the *Ranunculion fluitantis* and Callitricho-Batrachion vegetation Atlantic salmon *Salmo salar* Floating water-plantain *Luronium natans* Otter *Lutra lutra*
Clogwyni Pen Llŷn / Seacliffs of Lleyn	Vegetated sea cliffs of the Atlantic and Baltic Coasts
Pen Llyn a'r Sarnau / Lleyn Peninsula and the Sarnau	Sandbanks which are slightly covered by sea water all the time Estuaries Coastal lagoons * Priority feature Large shallow inlets and bays **Reefs** Mudflats and sandflats not covered by seawater at low tide Salicornia and other annuals colonizing mud and sand **Atlantic salt meadows** (*Glauco-Puccinellietalia maritimae*) Submerged or partially submerged sea caves Bottlenose dolphin *Tursiops truncatus* Otter *Lutra lutra* Grey seal *Halichoerus grypus*
West Wales Marine / Gorllewin Cymru Forol	Harbour porpoise (*Phocoena phocoena*)

SPA	Marine Feature
Liverpool Bay/ Bae Lerpwl (Wales/ England)	Red-throated diver *Gavia stellata* (in non-breeding season) Little gull *Hydrocoloeus minutus* (in non-breeding season) Common scoter *Melanitta nigra* (in non-breeding season) Waterbird assemblage Little tern *Sternula albifrons* (in breeding season) Common tern *Sterna hirundo* (in breeding season)
Traeth Lafan / Lavan Sands	Common oystercatcher *Haematopus ostralegus* (wintering) Eurasian curlew *Numenius arquata* (wintering) Great crested grebe *Podiceps cristatus* (wintering)
Anglesey Terns / Morwenoliaid Ynys Môn	Common tern *Sterna hirundo* Arctic tern *Sterna paradisaea* Roseate tern *Sterna dougallii* Sandwich tern *Sterna sandvicensis*
Glannau Ynys Gybi / Holy Island Coast	Red-billed chough *Pyrrhocorax pyrrhocorax*
The Dee Estuary (Wales/ England)	Northern Pintail *Anas acuta* Eurasian Teal *Anas crecca* Eurasian widgeon *Anas penelope* Sanderling *Calidris alba* Dunlin *Calidris alpina* Red Knot *Calidris canutus* Common oystercatcher *Haematopus ostralegus* Bar-tailed godwit *Limosa lapponica* Black-tailed godwit *Limosa limosa* Eurasian curlew *Numenius arquata* Great cormorant *Phalacrocorax carbo* Grey plover *Pluvialis squatarola* Common tern *Sterna hirundo* Little tern *Sterna albifrons* Sandwich tern *Sterna sandvichensis* Common Shelduck *Tadorna tadorna* Common redshank *Tringa totanus*
Glannau Aberdaron ac Ynys Enlli / Aberdaron Coast and Bardsey Island	Manx Shearwater *Puffinus puffinus*
Site of Special Scientific Interest (SSSI)	**Marine Feature**
Aber Afon Conwy	Estuaries Rockpools Soft piddock bored substrata
Pen y Gogarth / Great Ormes Head	Caves and overhangs Moderately exposed rock

	Rockpools Soft piddock bored substrata Under-boulders
Creigiau Rhiwledyn / Little Ormes Head	Caves and overhangs Moderately exposed rock Rockpools Soft piddock bored substrata Under-boulders
Traeth Pensarn	The coastal vegetated shingle beach
Gronant Dunes and Talacre Warren	Sanderling Calidris alba Great cormorant Phalacrocorax carbo Inter-tidal **Saltmarsh** Exposed sand
Dee Estuary / Aber Afon Dyfrdwy	**Saltmarsh** River lamprey *Lampetra fluviatilis* European smelt *Osmerus eperlanus* Sea lamprey *Petromyzon marinus* Atlantic salmon *Salmo salar* Otter *Lutra lutra*
Traeth Lafan	Common oystercatcher *Haematopus ostralegus* Red-breasted merganser *Mergus serrator* Eurasian curlew *Numenius arquata* Common redshank *Tringa totanus* **Eel grass** Moderately exposed sand Rockpools
Glannau Penmon- – Biwmares/Beaumaris	Caves and overhangs Mixed substrata Muddy gravel Soft piddock bored substrata Tide-swept algae Under-boulders
Arfordir Gogleddol Penmon	Caves and overhangs Moderately exposed rock Rockpools Soft piddock bored substrata
Puffin Island - Ynys Seiriol	Soft piddock bored substrata Under-boulders
Coedydd Afon Menai	Chalk and very soft rock
Glannau Porthaethwy	Caves and overhangs Mixed substrata Muddy gravel Rockpools Sheltered rock Tide-swept algae
Trwyn Dwlban	Lower Carboniferous rocks exposed on the foreshore, in coastal cliffs and in disused quarries.

	Pleistocene/Quaternary sediments exposed in coastal cliffs including excellent glacial striations exposed on the foreshore.
Traeth Lligwy	Rockpools
Llanbadrig - Dinas Gynfor	Precambrian rocks exposed in disused quarries, coastal cliffs and on the foreshore. Arenig-Llanvirn (Ordovician) rocks exposed in inland outcrops, coastal cliffs and on the foreshore. Caledonian structures (folds and fractures) exposed in coastal cliffs.
Cemlyn Bay	Percolation saline lagoon
Henborth	Pleistocene/Quaternary sediments exposed in coastal cliffs together with drumlin landform.
Carmel Head	Caledonian structures (folds and fractures) exposed in the coastal cliffs and on the foreshore.
Clegir Mawr	The nationally rare spotted rockrose, growing in one of its ten known British localities
Beddmanarch-Cymyran	Common ringed plover *Charadrius hiaticula* Common greenshank *Tringa nebularia* Inter-tidal **Saltmarsh** **Eel grass** Muddy gravel Sheltered mud Tide-swept algae
Glannau Ynys Gybi / Holy Island Coast	Inter-tidal Caves and overhangs Rockpools Under-boulders A sponge *Stryphus ponderosus*
Glannau Rhoscolyn	Inter-tidal **Saltmarsh** **Eel grass** Exposed rock
Ynys Feurig	Rockpools Under-boulders
Rhosneigr Reefs	Inter-tidal Caves and overhangs Rockpools Under-boulders
Ty Croes	Rockpools Surge gullies
Tywyn Aberffraw	Saltmarsh An amphipod *Gammarus chevreuxi*
Penrhynoedd Llangadwaladr	Exposed rock Rockpools Tide-swept algae Under-boulders

Newborough Warren - Ynys Llanddwyn	Northern Pintail *Anas acuta* **Saltmarsh** Moderately exposed sand Rockpools A bristleworm *Ophelia bicornis*
Malltraeth Marsh / Cors Ddyga	Open water associated with the lowland grazing marsh ditch system and former river meanders with associated plants and animals such as reed canary-grass, water-plantain and branched bur-reed. Club-rush, and reed sweet-grass are also dominant in parts. Submerged plants such as spiked water-milfoil, blunt-leaved pondweed, horned pondweed and uncommon plants such as flowering-rush, water-violet and marsh stitchwort are abundant. Pillwort – an aquatic fern Variable dragonfly A water beetle *Hydrochus brevis* Wintering shoveler An assemblage of breeding birds of lowland damp grassland such as lapwing, curlew, redshank and snipe. An assemblage of breeding birds of open water such as teal, gadwall, and pochard. Water vole
Morfa Dinlle	Coastal geomorphology of Wales
Y Foryd	Eurasian widgeon *Anas penelope* **Eel grass**
Dinas Dinlle	Pleistocene/Quaternary landform assemblage and associated subsurface stratigraphical profile
Gwydir Bay	Soft piddock bored substrata
Porth Dinllaen i Borth Pistyll	**Eel grass** Moderately exposed sand Rockpools
Porth Towyn i Borth Wen	Caves and overhangs Moderately exposed rock Rockpools
Glannau Aberdaron	Caves and overhangs Exposed rock Rockpools
Ynys Enlli	Caves and overhangs Exposed rock Rockpools Under-boulders

8.2 Appendix 2

Summary of spatial datasets used to identify marine habitats and invasive non-native species (INNS) within Welsh waters and the wider UK marine area.

Data Layer (A–Z)	Developed By	Brief Description of the Data
Environment (Wales) Act Section 7 and OSPAR: Marine Habitats (2019)	Natural Resources Wales	Spatial dataset showing the extent and location of marine habitats in Wales that are listed as habitats of Principal Importance under Section 7 of the Environment (Wales) Act 2016 and/or classified as threatened or declining under the OSPAR Commission. Includes habitats such as seagrass beds, maerl, Sabellaria reefs, saltmarsh, and oyster beds.
Intertidal Phase 1 Habitat Survey (2022)	Natural Resources Wales	Spatially referenced survey data of intertidal biotopes and communities across Wales. Includes mapped biotope polygons, target notes, access points, and photograph locations. Provides a snapshot of habitat distribution based on standard Phase 1 marine biotope mapping methodology.
JNCC Marine Habitat Data Product: EUNIS Level 3 Combined Map (2019)	Joint Nature Conservation Committee	Full-coverage map of EUNIS Level 3 seabed habitats across UK waters, integrating fine- and broad-scale habitat maps to present the best available information on habitat distribution. Used for marine protected area assessments and marine spatial planning.
JNCC Marine Habitat Data Product: OSPAR Threatened and/or Declining Habitats (2020)	Joint Nature Conservation Committee with data contributions from OSPAR Contracting Parties	Compilation of polygon and point records of OSPAR-listed threatened and/or declining habitats across the North-East Atlantic. Supports regional conservation assessments and excludes sensitive or restricted records.
Marine Article 17 Habitats Features (2018)	Natural Resources Wales	Snapshot of the most up-to-date mapped extent, location, and status of marine habitats listed under the EU Habitats Directive Annexes. Used for Article 17 reporting and updated every six years.

Data Layer (A–Z)	Developed By	Brief Description of the Data
Marine Invasive Non-Native Species (INNS) Pathways Heatmaps for Wales 2020 (2022)	Natural Resources Wales	2 km and 5 km resolution heatmaps identifying areas in Welsh waters at highest risk of marine invasive species introduction via shipping, boating, aquaculture, fishing, and offshore activities. Supports biosecurity planning and risk assessment.
NRW Distribution of the Invasive Non-Native Species American Slipper Limpet (*Crepidula fornicata*) in Conwy Estuary (2012)	Natural Resources Wales	Species distribution dataset mapping occurrences of the invasive American slipper limpet in the Conwy Estuary, used to assess local spread and ecological impacts.
Invasive Non-Native Species (INNS) Portal (2022)	Natural Resources Wales	Online portal providing open access to invasive non-native species records and alerts in Wales. Supplements the GB Non-native Species Secretariat information systems and supports implementation of the Great Britain INNS Strategy.

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