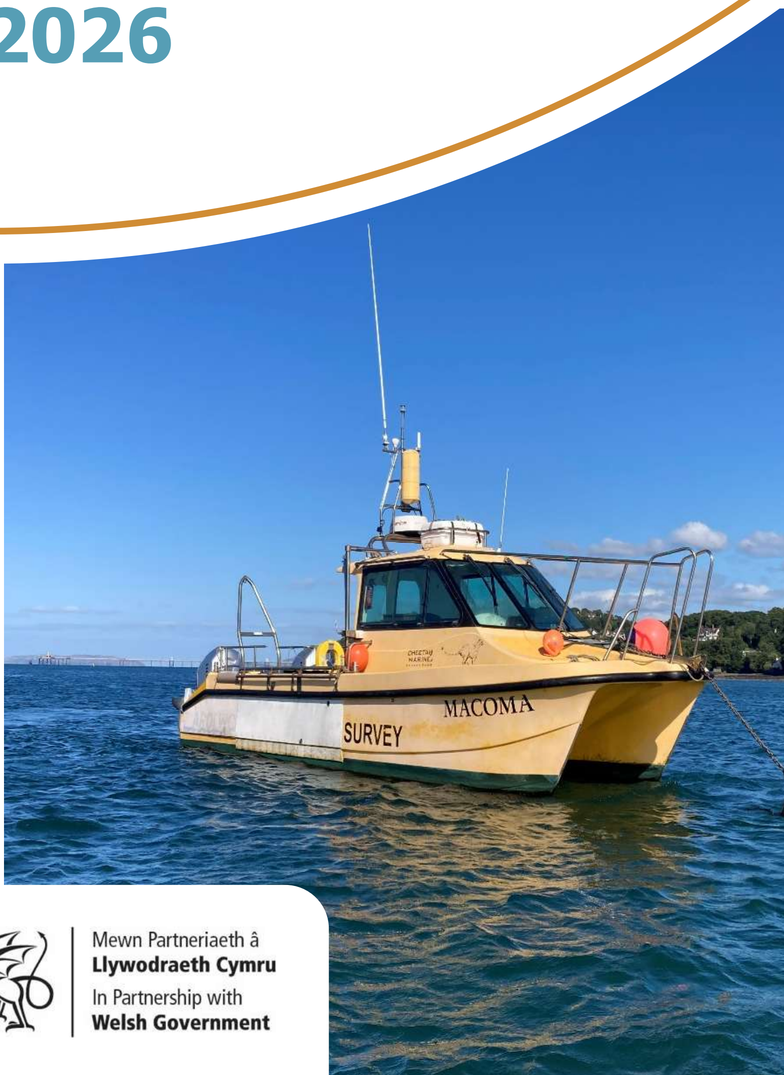
PRIFYSGOL BANGOR UNIVERSITY

ZSL Zoological Society of London

Habitat suitability modelling for restoration of *Ostrea edulis* in North Wales

May 2026



Cronfa Treftadaeth Heritage Fund

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In Partnership with Welsh Government

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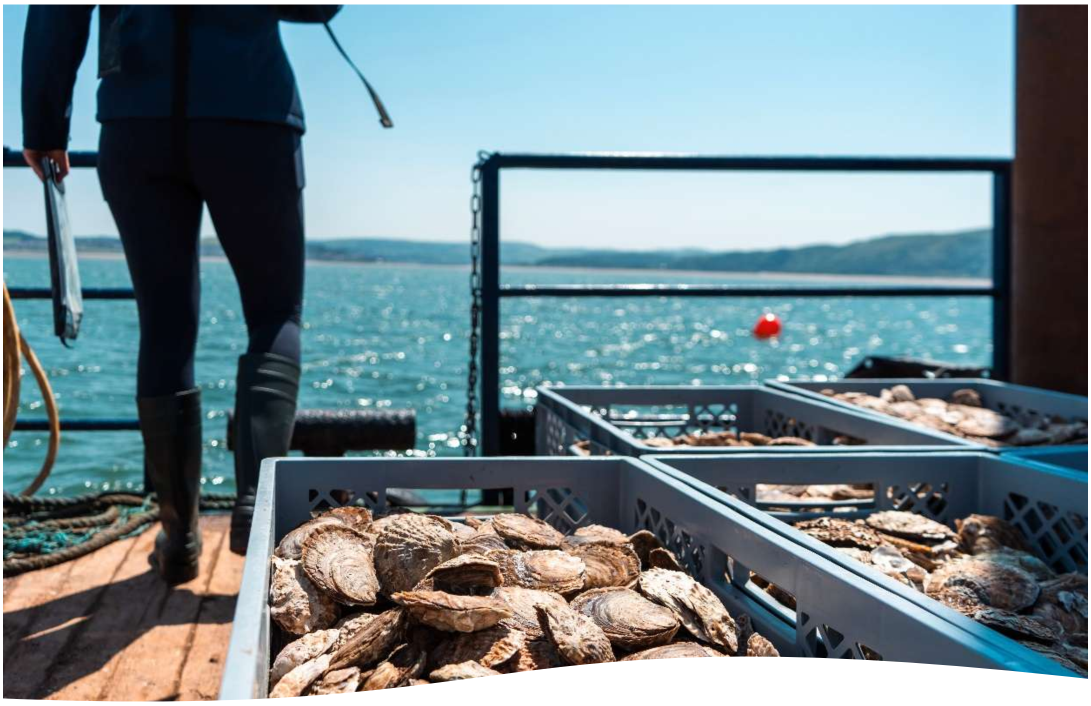


Crynodeb Gweithredol

Mae'r adroddiad hwn yn cyflwyno asesiad cychwynnol o addasrwydd cynefinoedd i helpu i ganfod ardaloedd a all fod yn addas i adfer wystrys brodorol (*Ostrea edulis*) ar hyd arfordir Gogledd Cymru. Mae riffiau wystrys brodorol wedi dirywio dros 95% yn y DU ac 1ha yn unig o gynefinoedd wystrys sy'n weddill yng Nghymru. Mae ymdrechion ar waith yn y DU a ledled Ewrop i ailadeiladu poblogaethau ac i adfer y gwasanaethau a'r prosesau ecolegol gwerthfawr a ddarperir gan y rhywogaeth.

Cafodd model addasrwydd cynefin cydraniad uchel (grid 30 m) ei ddatblygu drwy ddefnyddio'r data amgylcheddol sydd ar gael ar fathymetreg, cerrynt llanwol, straen croesrym y gwely, halwynedd, tymheredd, ocsigen, cloroffyl-a, gwaddodion mewn daliant a swbstrad gwely'r môr. Cafodd y setiau data hyn eu cyfuno â chofnodion achosion hanesyddol o wystrys i ganfod ardaloedd a allai fod yn addas ar gyfer goroesiad wystrys brodorol a datblygiad riffiau.

Mae allbwn y model yn dangos y gallai tua 3,276 km² ledled ardal astudiaeth Gogledd Cymru fod yn amgylcheddol addas i adfer wystrys brodorol. Mae'r ardaloedd a amlygwyd yn cynnwys rhannau o Fae Caernarfon, de Penrhyn Llŷn, dwyrain Ynys Enlli, rhan ogledd orllewinol Bae Tremadog i'r De o Bwllheli ac i'r dwyrain o Drwyn Cilan. Mae cofnodion wystrys hanesyddol ar y cyfan yn cyd-fynd â lleoliadau a nodwyd fel rhai a all fod yn addas, gan gadarnhau i raddau allbynnau'r modelu.

Roedd data cychwynnol a gasglwyd yn Nwyrain Afon Menai cadarnhau presenoldeb rhai cynefinoedd gwaddod cymysg a allai gynnal gwaith adfer. Fodd bynnag, amlygodd yr arolygon hefyd heriau ymarferol, gan gynnwys cerrynt llanwol cryf a chyfnodau byr o ddŵr llonydd, a all gyfyngu ar hyfywedd gwaith dosbarthu a monitro.

Ar hyn o bryd dylid edrych ar y canfyddiadau hyn fel rhai rhagarweiniol a bwriedir iddynt lywio ymchwil yn y dyfodol yn hytrach na diffinio safleoedd adfer. Bydd angen casglu rhagor o ddata ac ymgysylltu lleol ac asesu cyfyngiadau gweithredol a rheoliadol cyn rhoi blaenoriaeth i unrhyw safleoedd. Mae'r gwaith hwn yn rhoi sylfaen dystiolaeth gynnar fel rhan o'r prosiect *Cysylltu Conwy* i asesu'r potensial am y dyfodol am adferiad ar raddfa morlun o fewn ac yng nghyffiniau Afon Menai ac Ardal Cadwraeth Arbennig Bae Conwy.

Executive Summary

This report presents an initial habitat suitability assessment to help identify areas that may be suitable for restoration of the native oyster (*Ostrea edulis*) along the North Wales coastline. Native oyster reefs have declined by more than 95% in the UK and only 1ha of oyster habitat remains in Wales. Restoration efforts around the UK and across Europe, aim to rebuild populations and restore the valuable ecological services and processes the species provides.

A high-resolution habitat suitability model (30 m grid) was developed using available environmental data on bathymetry, tidal currents, bed shear stress, salinity, temperature, oxygen, chlorophyll-a, suspended sediments and seabed substrate. These datasets were combined with historic oyster occurrence records to identify areas that could potentially be suitable for native oyster survival and reef development.

The model output indicates that approximately 3,276 km² across the North Wales study area may be environmentally suitable for native oyster restoration. Areas highlighted include parts of Caernarfon Bay, south of the Llŷn Peninsula, east of Bardsey Island, northwestern part of Tremadog Bay to the south of Pwllheli and east of Cilan Head. Historic oyster records generally coincide with locations identified as potentially suitable, providing some support for the modelling outputs.

Initial ground-truthing in Menai West confirmed the presence of some mixed sediment habitats that could support restoration. However, surveys also identified practical challenges, including strong tidal currents and short slack-water periods, which may limit feasibility of deployment and monitoring.

These findings should be regarded as preliminary and are intended to guide further research rather than define restoration sites, at this stage. Additional ground-truthing, local actor engagement and assessment of operational and regulatory constraints will be required before any sites are prioritised. This work provides an early evidence base as part of the *Connecting Conwy* project to assess the future potential for seascape-scale recovery within and around the Menai Strait and Conwy Bay Special Area of Conservation.

Introduction

General state of *Ostrea edulis* populations in the UK

Populations of native oyster, or the European flat oyster (*Ostrea edulis*) 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. 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).

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.

When found in high densities, this species can act as an ecosystem engineer, forming complex, three-dimensional biogenic reefs (Morris *et al.,* 2019). Restoration efforts are underway in various regions around the UK and across Europe, aiming to rebuild populations and restore the valuable ecological services and processes oysters provide (Thomas *et al.,* 2022) (Figure 1). These include coastal protection through slowing wave and storm surge energy, improved water quality and clarity through the oyster's filter feeding efficiency, contributing to blue carbon cycling, and providing important sheltering, feeding, and nursery habitat for commercial fish species (Peterson *et al.,* 2003; Coen *et al.,* 2007; Lee *et al.,* 2020; Albentosa *et al.,* 2023). Increasingly, coastal habitats such as oyster reefs are being considered by governments as leading nature-based solutions to socio-environmental challenges such as poor water quality, coastal erosion and climate change. Active restoration is required to recover these diverse habitats from the scattered individual oysters remaining in Europe's waters.

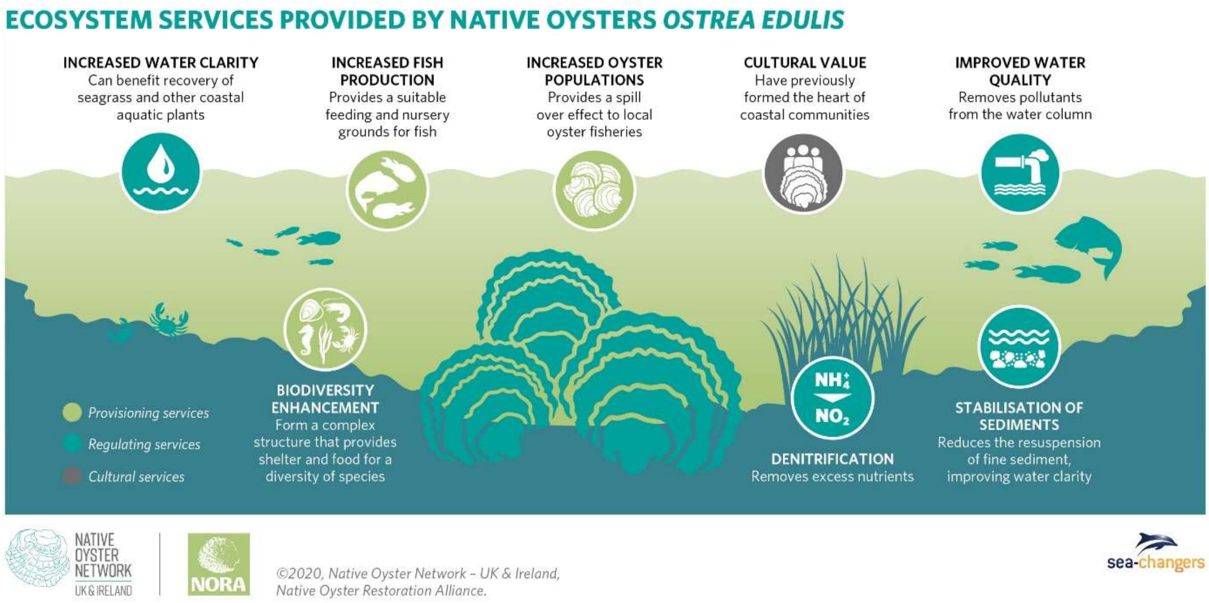


Figure 1. Ecosystem services provided by native oysters, Ostrea edulis. © Native Oyster Network- UK & Ireland, Native Oyster Restoration Alliance.

Historic records

Historical populations of native oysters had an average reef size of 30ha (Thurstan *et al.,* 2024). The North Wales coastline featured abundant native oyster beds, particularly during the 17th, 18th and early 19th centuries. Notable locations included the Menai Strait near Caernarfon and Beaumaris, areas off Puffin Island, and around Anglesey at sites such as Rhoscolyn and Llanddwyn Island (Hayden-Hughes *et al.,* 2023 and references therein).

These oyster beds were important to local coastal communities, serving as a significant food source and contributing to the Welsh economy. Welsh oyster boats reported landing 8,000 oysters daily, but up to 15,000- 20,000 oysters in some areas (White, 1894). Oysters have formed a part of the diet, with large quantities of native oyster shells discovered in Roman fortresses and Mesolithic archaeological remains in Wales (Wheeler and Pryce, 1926; Schulting and Richards, 2002).

Unfortunately, there are hardly any oyster habitats remaining in Wales, with only 1ha having been mapped; the locations of which are considered sensitive (NRW, 2020). There are currently no remnant native oyster populations found North Wales, however there are suitable habitats present to support this important and once present species. Recent restoration efforts aim to revive these historic oyster habitats, recognizing their ecological importance and potential to enhance resilience and the condition of the North Wales coastline.

Ongoing restoration efforts

The *#NNF2 Restoring Wild Oysters to Conwy Bay project* (2023–2025), delivered in partnership by 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 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, small-scale single-species interventions to coordinated, seascape-scale restoration across the mosaic of connected habitats that together define this coastline (Preston *et al.,* 2025; zu Ermgassen *et al.,* 2025), in line with the principles set out in the Lawton Review (Lawton *et al.,* 2010)

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.

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 a widely applied as an initial tool for assessing site suitability in coastal habitat restoration, including for native oyster (Armstrong *et al.,* 2021; Pogoda *et al.,* 2023; Stechele *et al.,* 2023; EA, 2024; Pereiro *et al.,* 2025 etc.) (Figure 2). Restoration handbooks and best-practice guidelines such as Preston *et al.,* (2020) and Hughes *et al.,* (2023), often recommend the use of HSMs (where available) to support initial site selection. However, the usefulness of these outputs depends on the spatial resolution and accuracy of the underlying data.

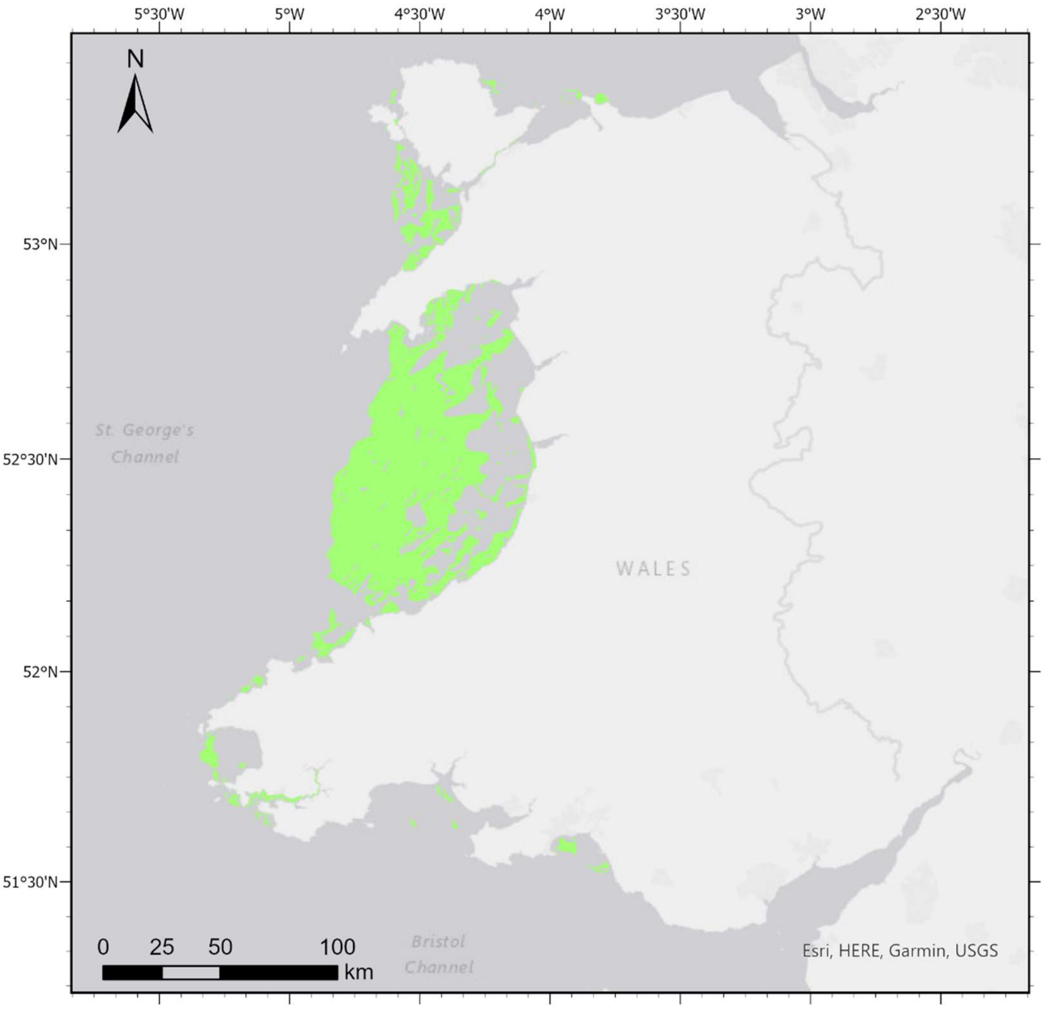


Figure 2. Native oyster potential restoration areas in Wales (within the model extent of 0 to 80 m depth) from NRW, 2026. Contains Natural Resources Wales information © Natural Resources Wales and Database Right. All rights Reserved. This includes some information based on data provided by: © European Union, 1995-2026. Copyright © 2020-2026, GEBCO. © JNCC and other data providers as set out in their data inventory.

Purpose of the report

The purpose of this report is to identify areas that may be suitable for the restoration of native oyster beds along the North Wales coastline, within and surrounding the Conwy Bay and Menai Strait region. A range of oceanographic, geologic and biophysical data is used to characterise suitable sites. This work will contribute to a field campaign as part of the *#NNF3 Connecting Conwy: A plan for seascape scale recovery of coastal habitats in Conwy Bay and the Menai Strait* to ground-truth habitat suitability, identifying knowledge gaps and data limitations when modelling is applied to localised fine-scale regions.

Study area

The study examines the North Wales coastline, within the eastern Irish Sea, extending from northern Cardigan Bay to Liverpool Bay (52.2°N to 53.6°N and -5.2°E to -2.5°E). The area is characterised by pronounced spatial heterogeneity, with physical conditions varying over relatively short distances. The area encompasses a wide range of water depth and habitats, ranging from extensive intertidal mud- and sand flats between Anglesey and Liverpool Bay to deep and more quiescent waters off to the east of Anglesey where water depths exceed 120 m.

Regional hydrodynamics are primarily driven by tidal forcing, which generates strong currents and maintains a well-mixed water column throughout the year. The tidal regime is macrotidal, with ranges exceeding 8 m in places. The strongest currents occur near exposed headlands with steep bathymetric gradients, particularly around northwest Anglesey, where velocities can exceed 3 m s^{-1}. In contrast, much of the nearshore zone is relatively shallow, with depths generally less than 10 m within 1 km of the coastline. Extensive intertidal areas are a key feature of the region, especially toward Liverpool Bay, where large mudflat and sandflat systems are exposed during low tide. Offshore, conditions differ markedly: to the east of Anglesey, water depths exceed 100 m and hydrodynamic conditions are comparatively less energetic. This combination of energetic headlands, sheltered embayments, and transitional coastal zones creates a wide range of hydrodynamic environments. These variations strongly influence sediment distribution, resulting in a mosaic of seabed types ranging from fine-grained depositional sediments to coarser, mobile substrates.

The North Wales coastline is also subject to significant anthropogenic pressure. Activities include commercial and recreational navigation, supported by major port infrastructure such as Holyhead, as well as fisheries, tourism, and coastal defence developments. In addition, offshore renewable energy installations have expanded in recent years. These combined pressures have contributed to habitat alteration and degradation, particularly affecting vegetated coastal ecosystems. While the area is subject to many pressure, many protections levels have been set in place in effort to protect its marine ecosystem with 8 Special Protection Areas (SPAs) including Liverpool Bay SPA; 8 Special Areas of Conservation (SACs) including Menai Strait and Conwy Bay SAC; and 41 Sites of Special Scientific Interest (SSSIs) including Glannau Rhoscolyn SSSI, and Porth Ceiriad, Porth Neigwl ac Ynysoedd Sant Tudwal SSSI. Consequently, the region provides a relevant and representative setting for assessing habitat suitability and restoration potential for the native oyster, *O. edulis*.

Method

Data acquisition

All data fields were interpolated to a common high-resolution grid covering the study domain, extending from 52.55° N to 53.65° N and -5.2° W to -2.5° W with a longitudinal resolution of 1/2000° and a latitudinal resolution of 1/4000° (around 30 m horizontal resolution). This high resolution was chosen to retain as much data detail especially in the nearshore region as possible as the North Wales coastline is complex, and small-scale changes in bathymetry and seabed substrate occur which would be lost with coarser resolution gridding. All datasets were interpolated onto this grid using linear interpolation.

Environmental data

Environmental data were compiled from multiple sources to maximise spatial resolution and were subsequently harmonised onto a common 30 m resolution grid for the North Wales study area using interpolation

Bathymetry

Bathymetry data comes from Ward *et al.,* (2023) and is a compilation of data from EMODnet (www.emodnet-bathymetry.eu, 2018 EMODnet Digital Terrain Model;

resolution of 1/16 × 1/16 arc minutes, 115 m) and the UK Hydrographic Office ADMIRALTY Marine Data Portal (www.admiralty.co.uk) (2–4 m horizontal resolution UK Hydrographic Office multibeam data); see Ward *et al.,* (2023) for details. For this report, the data from the R50 (<50 m horizontal model resolution in the near-shore area) model grid in Ward *et al.,* (2023) were interpolated to a regular spaced grid using linear interpolation.

Tidal velocities

Mean depth-averaged tidal velocities were obtained from Ward *et al.,* (2023). Tidal velocities were simulated with TELEMAC-2D on an unstructured mesh grid (R50 in Ward *et al.,* 2023) and simulate an average 28-day tidal cycle. For more information on the hydrodynamic model set-up and validation, please see Ward *et al.,* (2023). The data were interpolated to a regular spaced grid using linear interpolation.

Bed shear stress

Tidally-driven maximum bed shear stress (bss_t) was calculated from peak tidal velocities from Ward *et al.,* (2023) (see *tidal velocities* for details) as where ρ is density set to 1025 kg/m^3 and uv_f is the friction velocity.

$$bss_t = \rho\, uv_f$$

Wave-driven bed shear stress (bss_w) was estimated using winter monthly mean significant wave height (H_s) and period (T) from Neill (2024). The underlying wave model is SWAN run in a nested setup with a lower resolution North Atlantic setup and a high resolution (1/120 x 1/202°) Irish Sea model for the period 2014 to 2020. The wave induced bed shear stress (bss_w) was calculated as:

$$bss_w = \frac{1}{2}\rho\, f_w {U_b}^2$$

where $f_w = 0.02$ is the wave friction factor and U_b is the near-bed orbital velocity amplitude. U_b was estimated using the empirical formulation of Soulsby (1997):

$$U_b = \frac{H_s}{2}(\frac{g}{h})^{1/2}\exp\left[-(4.41\frac{h}{\sqrt{gT}})^{2.45}\right]$$

Where $g = 9.81$ m/s² is the gravitational acceleration and h is the water depth. The exponential term accounts for finite-depth attenuation, with coefficients derived from empirical fits to linear wave theory.

To account for nonlinear interactions between waves and tidal currents, the combined wave–current bed shear stress (bss_{wc}) was estimated following the parametrisation of Soulsby (1997), which provides a direction-averaged approximation of the original model of Grant and Madsen (1979):

$$bss_{wt} = bss_t\sqrt{1 + 1.2\frac{bss_w}{bss_t} + (\frac{bss_w}{bss_t})^2}$$

Total suspended matter

Satellite derived mean total suspended matter data was obtained from EMODnet (EMODnet, 2025). The data has a horizontal resolution of 0.00314° in longitude and latitude. The data were interpolated to the high-resolution grid using linear interpolation. This dataset does not fully cover nearshore areas, resulting in data gaps close to the coastline.

Salinity and temperature

Salinity and bottom temperature data was extracted from the Copernicus Marine Service Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast product (Copernicus Marine Service, 2025b). The data has a resolution of 1/36° and data spanning full years was available for 2023 and 2024. Bottom temperatures and salinities were extracted for the study area and interpolated to the high-resolution 30m grid using linear interpolation. Here, monthly mean data was used from which annual means, minima and maxima were calculated.

Oxygen concentrations

Oxygen concentrations were extracted from the Copernicus Marine Service Atlantic - European North West Shelf - Ocean Biogeochemistry Analysis and Forecast product (Copernicus Marine Service, 2025a). The data has a resolution of 1/36° and data spanning full years was available for 2023 and 2024. Bottom oxygen concentrations were extracted for the study area and interpolated to the high-resolution grid using linear interpolation. Here, monthly mean data was used from which annual means, minima and maxima were calculated.

Chlorophyll concentrations

Monthly mean chlorophyll concentrations were extracted from the High-Resolution Ocean Colour (HR-OC) Consortium (Brockmann Consult, Royal Belgian Institute of Natural Sciences, Flemish Institute for Technological Research) which distributes Level 4 (L4) chlorophyll-a concentration (CHL, expressed in µg/l) for the Sentinel 2/MSI sensor at 100m resolution for a 20km coastal zone (Copernicus Marine Service, 2025c). The monthly mean data was used to calculate annual means, minima and maxima which were interpolated to the high-resolution grid using linear interpolation.

Seabed sediment data

Seabed sediment data were compiled from Smeaton et a l. (2021, Supplementary Materials https://www.frontiersin.org/articles/10.3389/feart.2021.593324/full#supplementary-material; Table 1.xlsx). The dataset aggregates habitat surveys, the European Nature Information System (EUNIS), and additional records from the UK Hydrographic Office and the British Geological Survey. Sediments were classified using a modified Folk classification scheme (Folk, 1954; Kaskela *et al.,* 2019), which categorises seabed material into 16 classes based on proportions of mud (<63 µm), sand (63–2000 µm), and gravel (>2000 µm) with additional categories indicating shell presence. The mean spacing between sediment samples is ~270 m across the study area, decreasing to ~110 m within 100 m of the coastline. Point observations were interpolated onto the 30 m grid using nearest-neighbour interpolation to produce categorical substrate maps.

Percentage of gravels was derived from these classifications; however, the discrete nature of the Folk16 scheme (five classes of percentage of gravels) results in spatial discontinuities. To improve suitability for habitat modelling, percentage of gravels were refined by assuming higher gravel fraction in sandy sediments relative to muddy sediments. Furthermore, point data where shells were recorded were extracted additionally. The point data was gridded to the high-resolution grid using nearest neighbour interpolation as a presence/absence mask.

Historic occurrence data

Historic records of native oysters were compiled from Hayden-Hughes *et al.*, (2023) and Thurstan *et al.,* (2024). Locations were plotted for the North Wales coastline and then refined according to the location and bed descriptions.

Suitability criteria

Habitat suitability criteria were compiled for *Ostrea edulis* for a range of variables and extracted from the reports compiled by Smaal *et al.,* (2017), Perry and Jackson (2017), and Hayden-Hughes *et al.,* 2026. These are summarised in Table 1. As data was not necessarily a 1:1 equivalent to the baseline reports or details of the data were unclear (e.g., for bed shear stress), some adjustments of the suitability criteria had to be made to achieve equivalence as closely as possible. For a number of variables (e.g., oxygen concentrations) the whole study area was deemed suitable, but unclarities existed with regards to what exact metrics were used in the original report (e.g., daily means, monthly means or annual means). The column *Notes* details which metrics were selected for this report.

Table 1. Summary of Environmental factors determining O. edulis habitat suitability.

ENVIRONMENTAL FACTOR	SUITABLE RANGE	NOTES
Water depth (m)	>-79 m and <-1m	Water depth below mean sea level
Sediment composition	Sand and mud with gravel and/or shell present; shells; gravel; rock and boulders	Classified according to Folk16 scale
Total suspended sediment (mg/l)	< 60 mg/l	
Maximum sea bed shear stress (N/m2)	0.125-2.5 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 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.
Salinity (psu)	>25 psu	
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.
Oxygen concentration (mg/l)	>3.5 mg/l	Annual mean of monthly mean oxygen concentrations used
Chlorophyll concentrations (µg/l)	>1.68 µg/l	

Habitat suitability determination

For each environmental variable, maps were generated which distinguished between suitability criteria met (value of 1) and suitability criteria not met (value of 0). From the individual environmental suitability criteria, combined habitat suitability metrics were established in two ways: (1) binary suitability maps were established by multiplying all the individual variable suitability maps to give an overall yes/no map (value of 1 for suitable, value of 0 for unsuitable). (2) percentage suitability maps were generated by multiplying all the individual variable suitability maps to give and overall yes/no map (value of 100% for suitable down to a value of 0% for unsuitable).

Results

Combined habitat suitability maps: hydrodynamics

The habitat suitability model identified 3,276 km^2 potentially suitable for *O. edulis* within the study area. Figure 3 shows binary habitat suitability (i.e., suitable or not suitable) based on hydrodynamic variables only. Generally, near-shore regions are unsuitable due to a combination of shallow water depths, too high or too low current speeds and bed shear stress values. To the north of Anglesey, to the west of the Llŷn Peninsula and in parts of the Menai Straits, very strong tidal currents render the region unsuitable for oysters. Areas identified as suitable are located offshore of the coastline stretching between the northeastern tip of Anglesey and Liverpool Bay, with smaller suitable areas close to the coast in Red Warf Bay, the Menai Strait and Conwy Bay and the Rhyl Flats. Furthermore, Holyhead Bay shows widely suitable conditions. Large parts of Caernarfon Bay away from the near-shore regions which are unsuitable to high bed shear stresses are classed as suitable. To the south of the Llŷn Peninsula, only the western parts of Tremadog Bay are classed as suitable. In the northwest, very low current speeds render the habitat unsuitable, whereas in the southwest, bed shear stress values are exceeded.

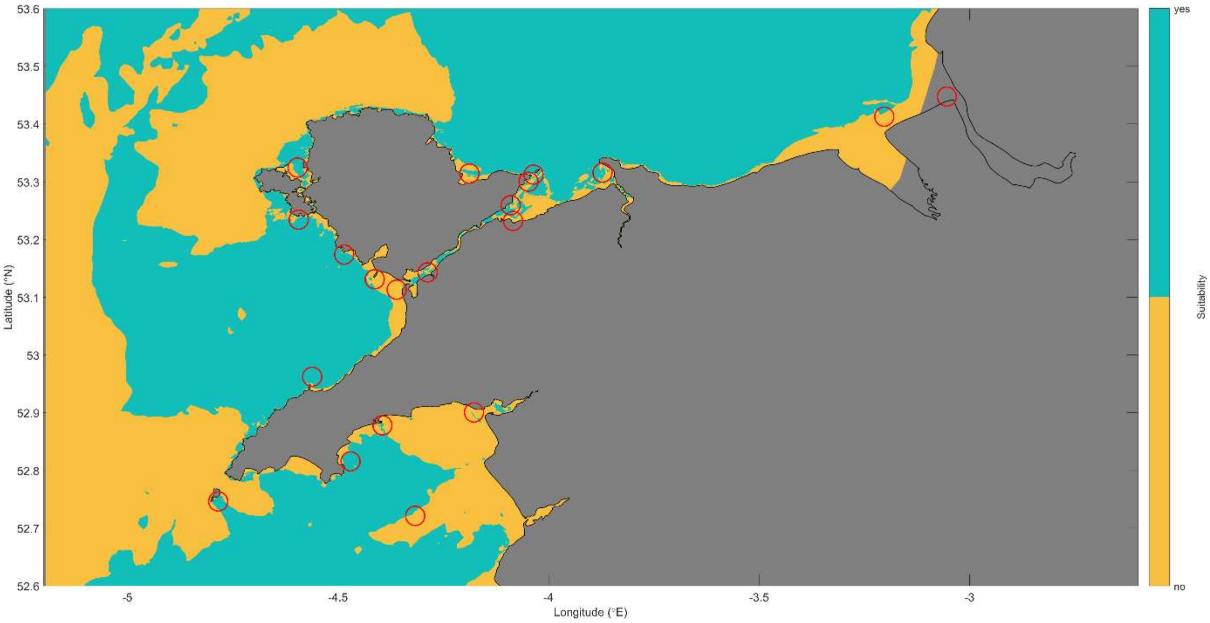


Figure 3. Habitat suitability based on hydrodynamics only (water depth, current velocity, bed shear stress, total suspended matter and salinity). Red circles indicate approximate locations of historic oyster beds.

Generally, locations for which records of historic oyster beds are present are classed as suitable based on hydrodynamic conditions. However, it is worth noting that there are some uncertainties in the identification of the exact location of the historic oyster beds, e.g., the historic bed located at the western entrance of the Menai Strait. Here, for example, the record contains the following description: "[Carnarvon] The oyster fishery used to be of some importance. There is a bank off the southern mouth of the Straits, in nine fathoms of water, which used to make a capital dredging ground. The area of this bank is about half a-mile square, and the sides fall abruptly into deep water. But little is done in oyster fishing now" (Thurstan *et al.,* 2024).

Note that the variables that are most important in determining suitability from a hydrodynamic viewpoint are bed shear stress and current speed. Suitability is therefore highly dependent on the cut-off limits chosen for these variables. See individual variable maps in the Appendix A for more details.

Combined habitat suitability maps: Sediments and hydrodynamics

Sea bed sediments vary widely across the study area (Figure 4) and the suitability classification is highly sensitive to the choice of suitable substrate classes. Here, soft muddy and sandy sediments (M = Mud, sM = sandy Mud, mS = muddy Sand and S = Sand) have been deemed unsuitable. Because oysters require some type of hard substrate (e.g., gravel beds, boulders, shells) to attach, their presence has been set to allow the substrate to be suitable.

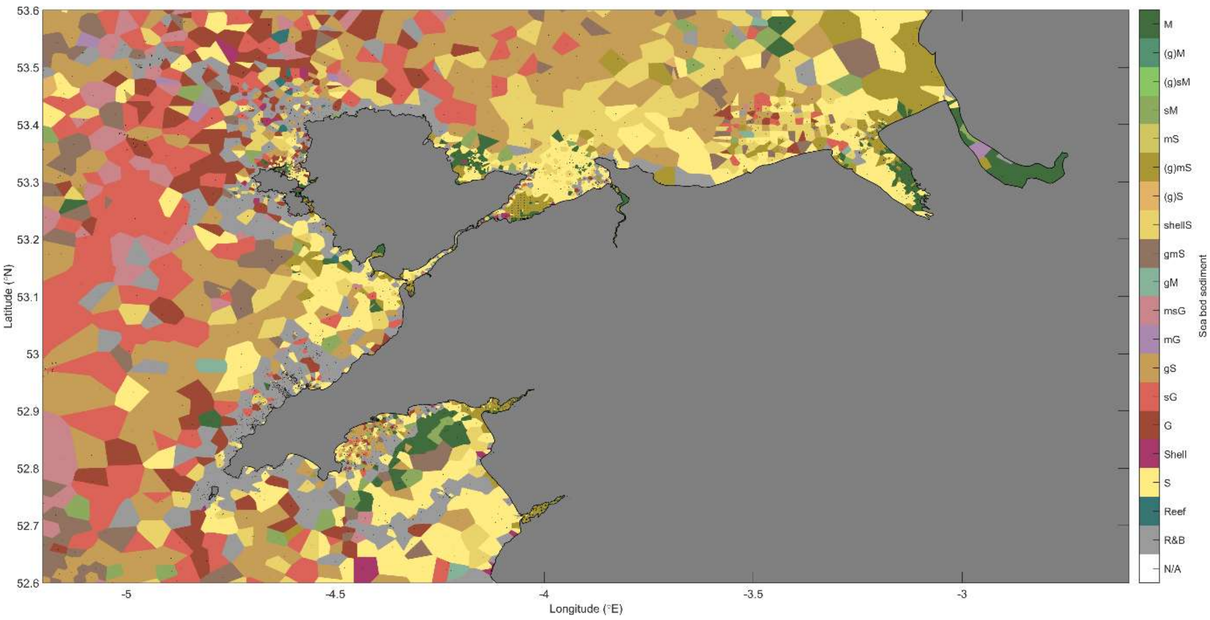


Figure 4. Seabed sediment classification according to the Fold16 scale.

In near-coastal areas, the high degree of sediment heterogeneity leads to a highly patchy pattern of suitable habitat locations (Figure 3). Generally, the presence of historical beds corresponds with areas of suitable sea bed substrate (e.g., northeastern Menai Strait, Caernarfon Bay, Conwy Bay, Bardsey Island and Bardsey Island). Note that here pure sand has been excluded as a suitable substrate type due to its high degree of sediment mobility. Combined with the hydrodynamic maps, overall habitat suitability maps can be obtained (see Figures 5 and 6).

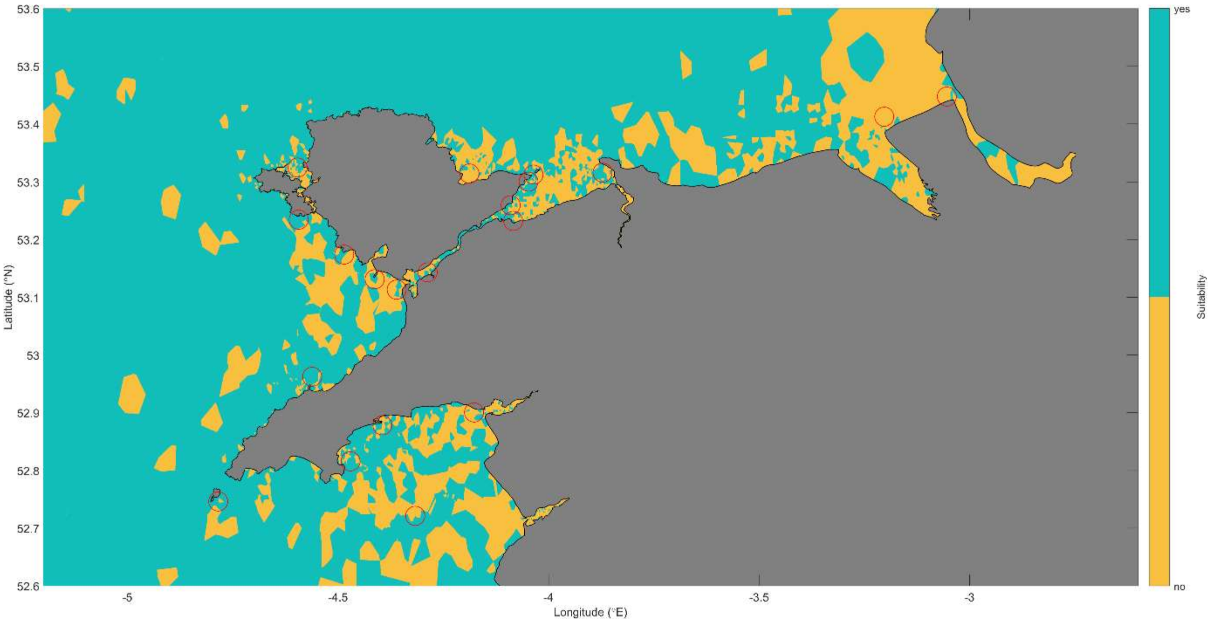


Figure 5. Habitat suitability based only sediment classification. Red circles show historical oyster beds

From south to north, suitable habitat areas are found to the south of the Llŷn Peninsula and to the east of Bardsey Island. Furthermore, the northwestern part of Tremadog Bay to the south of Pwllheli and east of Cilan Head is deemed suitable. Large parts of Caernarfon Bay are classed as suitable.

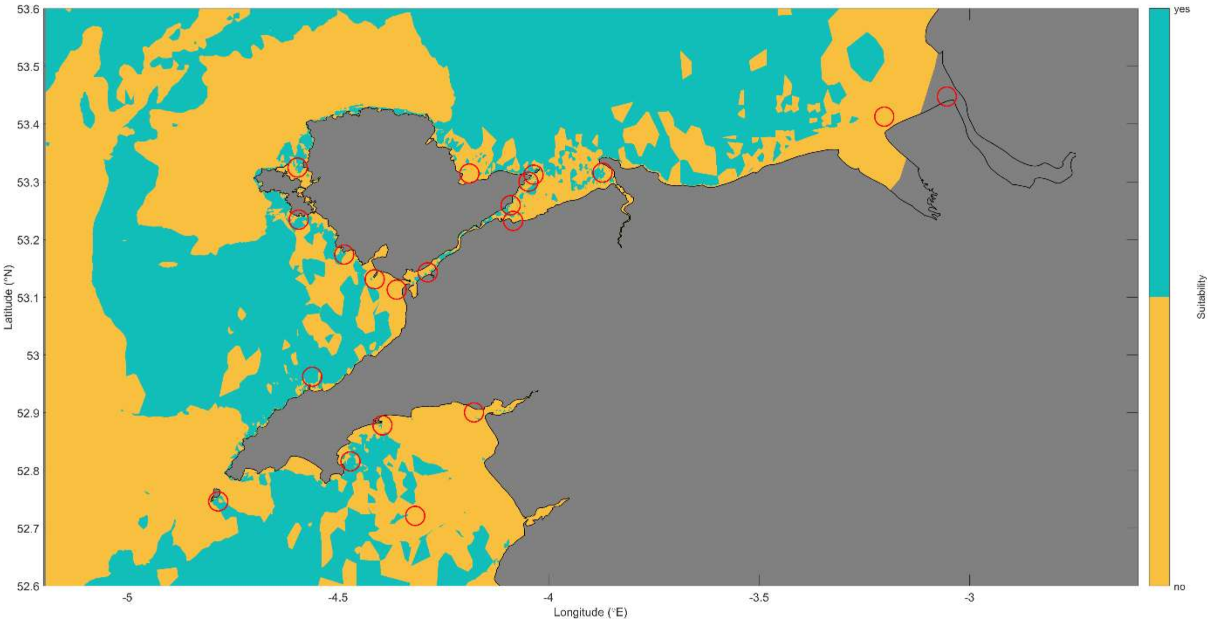


Figure 6. Combined habitat suitability based on hydrodynamics and seabed substrate. Red circles denote historical oyster beds.

Ground-truthing

Initial ground-truthing was undertaken to verify the outputs of the habitat suitability model and to assess whether areas predicted to be highly suitable for restoration of the native oyster, European flat oyster, exhibited site conditions consistent with successful reef establishment and long-term persistence. The purpose of this process was to inform validation of fine-scale model predictions.

The habitat suitability model output extends from northern Cardigan Bay to Liverpool Bay, but this initial ground-truthing exercise focused on the Menai Strait and Conwy Bay SAC.

Collation of existing datasets

A comprehensive site assessment considered any significant anthropogenic activities that may affect restoration success, including dredging, aggregate extraction, and other seabed disturbances. The presence of marine assets such as submarine cables, and pipelines was assessed to avoid conflicts with infrastructure. Ecological risks must be evaluated, particularly within a disease control area for *Bonamia ostreae* (CD 09.2011) which can affect native oyster survival and be a consideration when sourcing oysters. Proximity to historical oyster reefs was examined as can indicate favourable habitat conditions. Existing nature conservation designations was considered, which may provide both opportunities and regulatory constraints. Fishing regulations were reviewed to determine existing protections (inshore fisheries legislation).

The native oyster potential suitability map was overlaid with existing data layers sourced from DataMap Wales. Factors including significant activities (navigational dredging, ports and harbours), fishing regulations (several and regulating orders), existing nature conservation designations (MPAs) and historical and maritime assets (designated wrecks and scheduled monuments) were assessed within this region (Figure 7).

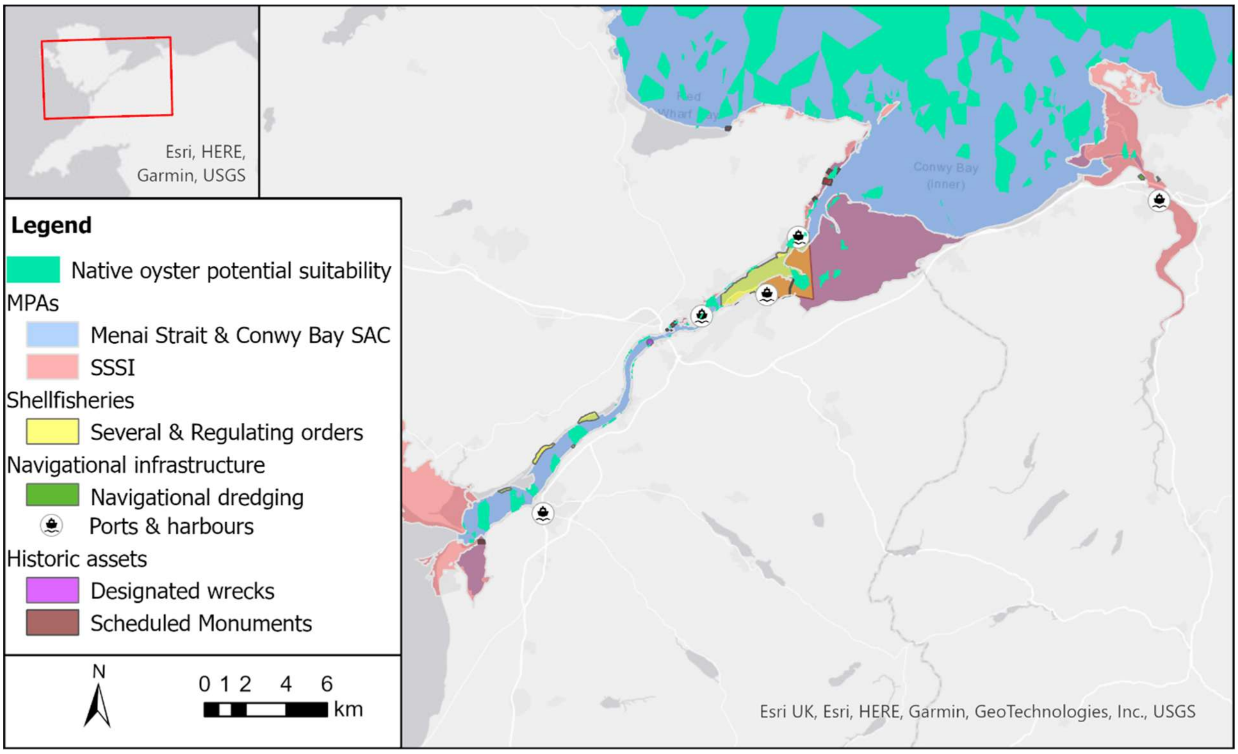


Figure 7. Map of the native oyster potential suitability areas (green) within the Menai Strait and Conwy Bay SAC overlaid with data layers for MPAs, shellfisheries, navigational infrastructure, and historic assets. Contains public sector information licensed under the Open Government Licence v3.0. (Data source: DataMap Wales).

The ground-truthing survey areas were selected through a process of elimination, considering logistical and environmental constraints. Restoration is recommended in areas known to have supported native oyster populations however there are further criteria that need to be considered (Preston *et al.,* 2020). Areas within or near SSSIs were avoided because of the potential environmental impact of restoration activities (cultch translocation) and logistical challenges. Important shellfisheries, historical assets and areas near navigational/ maintenance dredging areas were avoided. However, proximity to ports and harbours can be a constraint (increased maritime traffic) and beneficial for restoration activities (vessel availability, reduced mobilisation and demobilisation costs and cultch storage). Water depth was also an important consideration as monitoring can be challenging at deep restoration sites.

Menai West is a Shellfish Waters Protected Area (SWPA) designated by Welsh Ministers for the protection and support of shellfish growth. Good water quality is essential to produce high-quality shellfish and existing monitoring programmes are in place for each SWPA (Figure 8). Water quality is also important for restoration success and with existing monitoring data can be beneficial for site selection. Existing skill sets, knowledge and vessels of local fishers can be beneficial for restoration delivery and long-term monitoring.

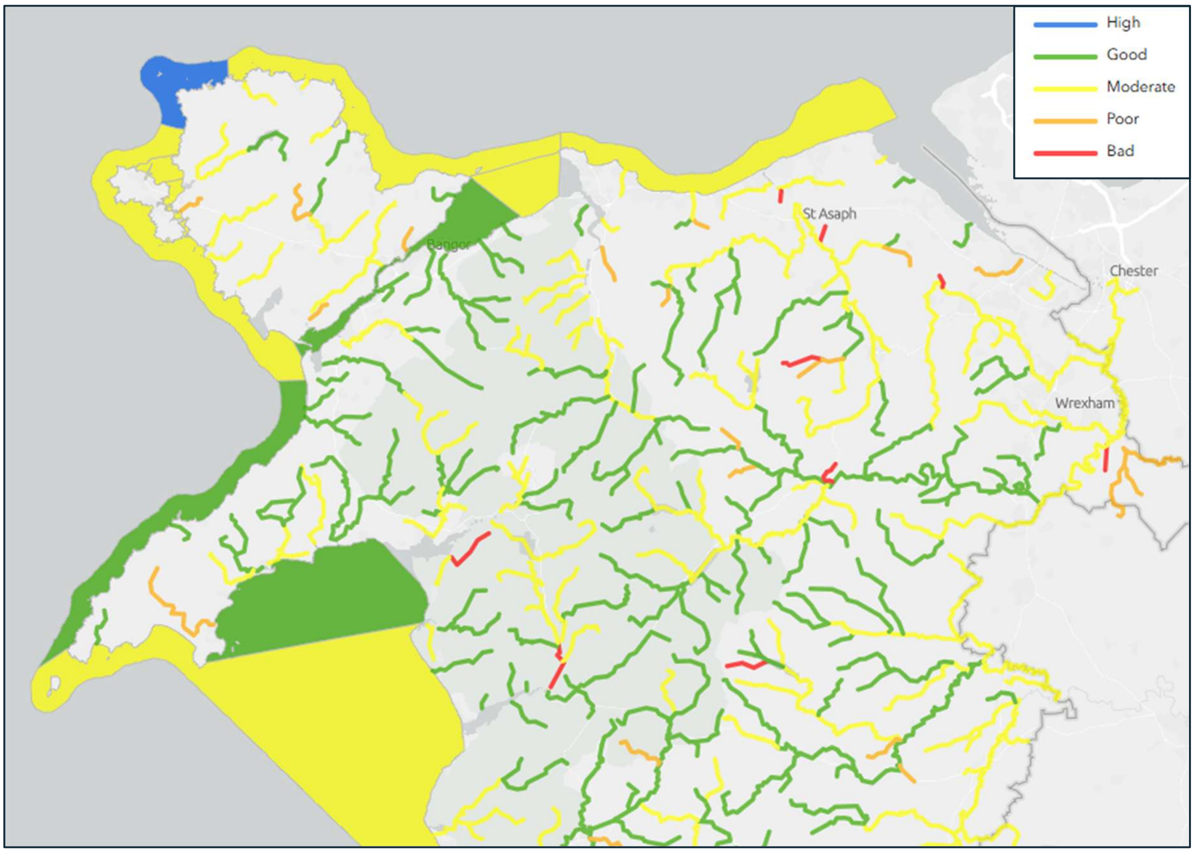


Figure 8. Water Watch Wales map provides information about each individual waterbody from Water Framework Directive (WFD) Regulations Cycle 3 Classification (Interim 2024) Rivers, Waterbodies and Coastal Water graded from high (blue) to bad (red) condition. Contains public sector information licensed under the Open Government Licence v3.0.

Field surveys

A small subset of locations in Menai West was selected for field assessment (Figure 9). Surveys were designed to evaluate the physical characteristics that are known to influence oyster survival, recruitment, and reef development. Parameters examined included substrate composition and stability, water depth, and the benthic communities present.

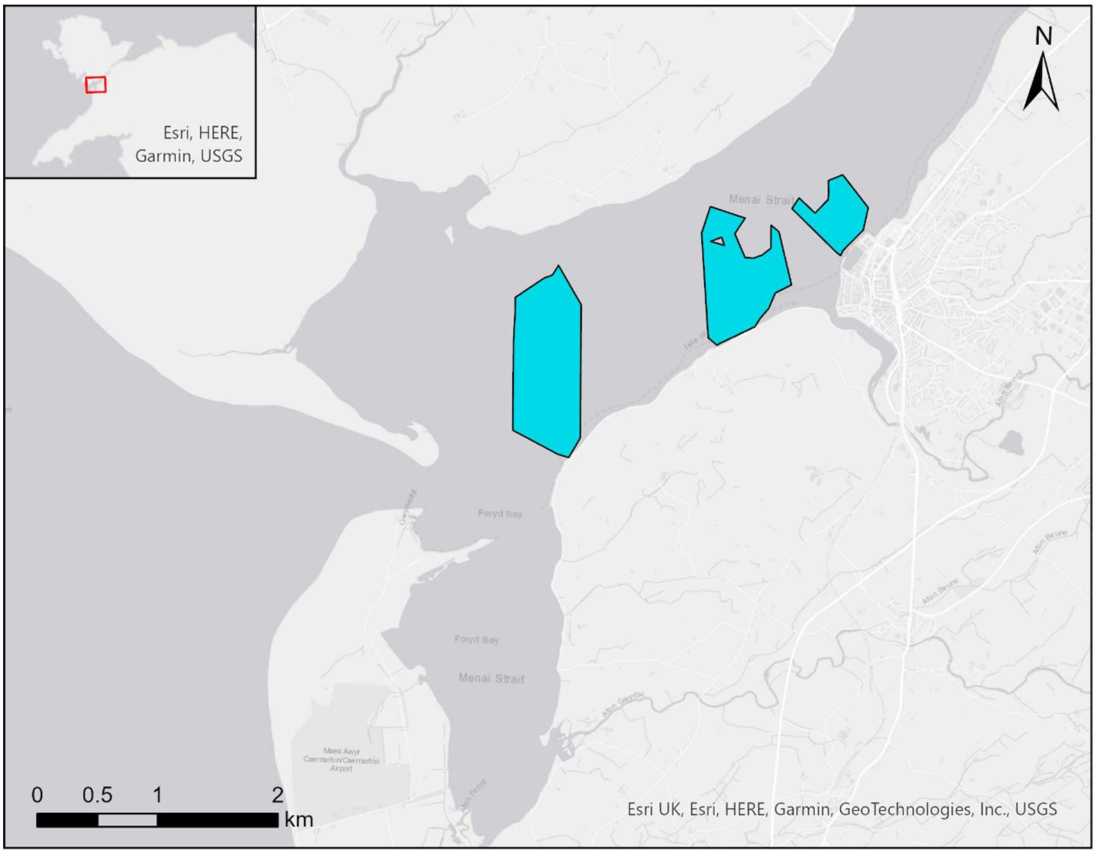


Figure 9. Map of subtidal potential suitability locations in Menai West selected for groundtruthing surveys.

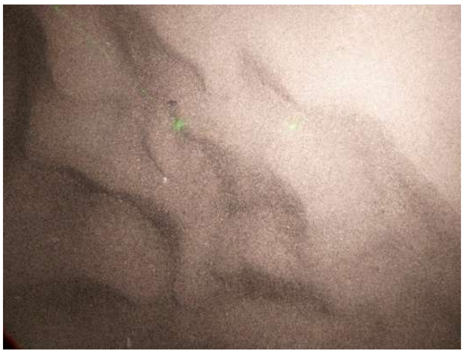
Field investigations were conducted using a combination of underwater video and acoustic seabed surveys, depending on site accessibility and water depth. Imagery was analysed to confirm the presence of firm substrates such as shell, gravel, and consolidated sediments, which provide suitable attachment surfaces for juvenile oysters. Areas dominated by unstable fine silts or heavily mobile sediments were considered less favourable, regardless of model predictions.

Biological assessments were also undertaken to identify potential ecological constraints and opportunities. Evidence of shell material, and associated reef fauna was recorded where present, as these features can indicate suitability and enhance restoration potential. Conversely, presence of invasive species, excessive macroalgal cover, or signs of poor water quality were noted as factors that could limit restoration success.

Results

From the still imagery analysis, it was recorded these areas of seabed in Menai West were largely comprised mobile 'subtidal sand' and 'subtidal mixed sediment' with encrusting taxa and a variety of infauna. Four habitats/ biotopes were observed. The substrate was largely comprised of 'Circalittoral fine sand' (SS.SSa.CFiSa), and silt covered pebbles and shells, recorded as 'Circalittoral mixed sediment' (SS.SMx.CMx). Large infaunal communities of polychaetes and burrowing anemone were recorded as 'Circalittoral muddy sand' (SS.SSa.CMuSa), and some presence of silt covered cobbles or boulders, recorded as 'Moderate energy circalittoral rock' (CR.MIR). Example images of the habitats/biotopes identified are provided in Table 2.

Table 2. Images illustrating the habitats/biotopes identified during the Menai West groundtruthing still imagery analysis.

SS.SSa.CFiSa	SS.SMx.CMx
	
SS.SSa.CMuSa	CR.MCR
	

The imagery was reviewed for the non-native species. The Chilean oyster, *Ostrea chilensis* was recorded in the imagery in low densities (Figure 10). The species is known to be present within the Menai Strait since being introduced in 1964.

Figure 10. Example of seabed image including non-native species, Ostrea chilensis.

Ground-truthing results were compared with model outputs to assess the degree of agreement between predicted and observed habitat conditions. Sites where field observations confirmed the presence of suitable substrate, subtidal mixed sediment could be favourable for restoration efforts and reef creation. Native oysters are a recognised biotope of subtidal mixed sediments (EUNIS code A5.435) and it is deemed as a preferential habitat type for oysters. However, during the survey work, it was noted that the period at the turn of the tide when there is little or no horizontal motion of tidal water, known as slack water, was short (approximately 20 minutes). This would pose a significant logistical challenge when delivering restoration activities and monitoring (deploying cultch, water clarity for imagery analysis, time for dive observations).

The ground-truthing surveys helped to inform validation of fine-scale model predictions, however it was concluded that these survey sites would not be suitable because of the logistical challenges posed. Further consideration and extensive ground-truthing would be needed.

Recommendations

The validation process provides an important quality assurance step, demonstrating the reliability of the habitat suitability model while identifying opportunities for model refinement. Incorporating field-based observations improves confidence in the final site selection and ensured that recommended restoration areas were supported by both spatial modelling and empirical evidence.

Extensive ground-truthing surveys are needed to reduce uncertainty and help refine the prioritisation of restoration sites. For example, salinity, temperature, oxygen concentration and total suspended matter were factors considered in the HSM but the data was derived from satellite imagery. Existing environmental conditions should be assessed to determine whether they meet the habitat requirements for oysters. Key parameters include salinity, turbidity, water quality, water depth, predominant sediment type, wave exposure, and tidal current speeds can be recorded using loggers. Additional survey techniques could also be applied such as grab sampling, and diver observations.

The intensity of recreational and commercial activities should be assessed. Particular attention to boating, mooring, fishing, trawling, and bait digging, as these activities can physically damage restored reefs. Data collection of marine and coastal recreation carried out in Southwest Wales by Pembrokeshire Coastal Forum would be a useful resource if available in other areas.

Short-term climate change implications could be incorporated into site selection and restoration planning. Relevant factors include projected sea level rise, increasing storm frequency and intensity, and associated changes in sediment dynamics and water quality. These influences may affect the stability and persistence of restored oyster reefs over time. However, long-term scenarios should not deter restoration trials taking place as provide key lessons learnt for future restoration efforts.

Consultation with local actors can provide valuable insights into historical oyster presence, site conditions, practical considerations, and current pressures. Early and sustained engagement with regulators, fisheries representatives, conservation organisations, and other interested parties is strongly recommended to identify constraints and build support and to codesign restoration activities. Restoration needs to be operational, place-based, and co-designed with fishers, recognising fisheries as part of the solution.

Land ownership and seabed rights should be confirmed at an early stage. In most cases, the seabed is owned by The Crown Estate, although local exceptions may apply. This is also a key consideration for accessing to the shoreline and transporting equipment. Prospective restoration practitioners should ensure that sufficient broodstock supply and cultch materials are available to support restoration efforts.

Following ground-truthing and consultation, sites can be ranked according to their overall suitability and the specific drivers of the project. Ranking criteria may include environmental suitability, ecological risk, likelihood of long-term persistence, logistical feasibility, local support, and regulatory complexity.

This process enables restoration practitioners and collaborators to identify the most suitable locations for native oyster restoration and to prioritise sites with the greatest probability of ecological and operational success.

Conclusion

The habitat suitability assessment indicates that there are areas along the North Wales coastline where environmental conditions may be suitable for the restoration of native oyster (*Ostrea edulis*) habitat. The overlap between modelled suitable areas and historical oyster records suggests that the model is identifying locations with characteristics consistent with those that have previously supported oyster populations.

However, the results also demonstrate that environmental suitability does not necessarily equate to restoration feasibility. Initial ground-truthing in Menai West identified habitats that may be capable of supporting oysters, but also highlighted practical constraints, including strong tidal currents and short slack-water periods, which would make restoration and monitoring more challenging. Other factors not fully captured by the model, such as seabed disturbance, water quality, disease risk, local actor priorities and regulatory requirements, will also influence site suitability.

Taken together, the findings suggest that there is potential for native oyster restoration within Menai Strait and Conwy Bay SAC, but that further work is required before specific sites can be selected with confidence. Habitat suitability modelling has proved to be a useful tool for identifying areas for investigation, but it should be used alongside detailed field surveys and consultation with relevant parties.

This work provides an early evidence base as part of the *Connecting Conwy* project to assess the future potential for seascape-scale recovery within and around the Menai Strait and Conwy Bay Special Area of Conservation. Further ground-truthing, local actor engagement and site appraisal is needed to identify locations that offer the best balance of environmental suitability, practical feasibility and long-term restoration potential.

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Appendix A

Environmental variability

Maps outputs to display variability of environmental factors determining *Ostrea edulis* habitat suitability: Bathymetry (Figure A1), TSM (Fig. A2), Mean tidal speed (Fig. A3), Combined bed shear stress (Fig. A4), Salinity (Fig. A5), Sediment type (Fig. A6), Minimum monthly mean temperatures (Fig. A7).

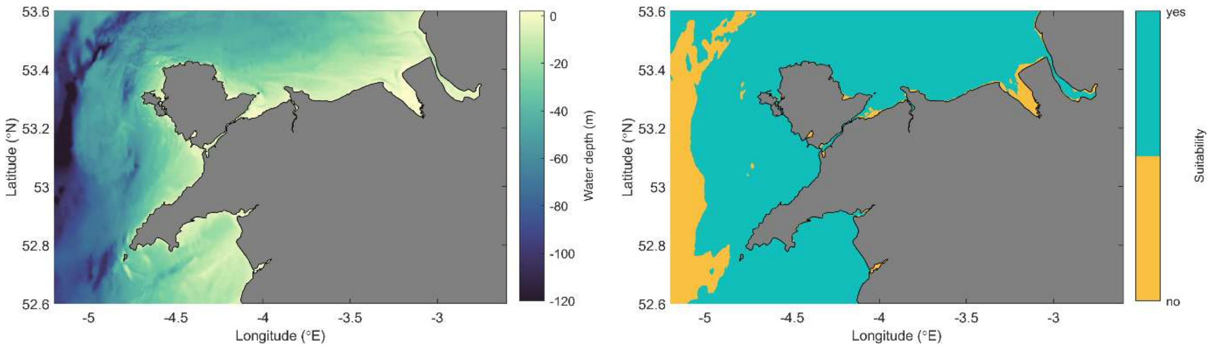

Figure A1. (left) Bathymetry of the North Wales coastline. (right) Related habitat suitability.

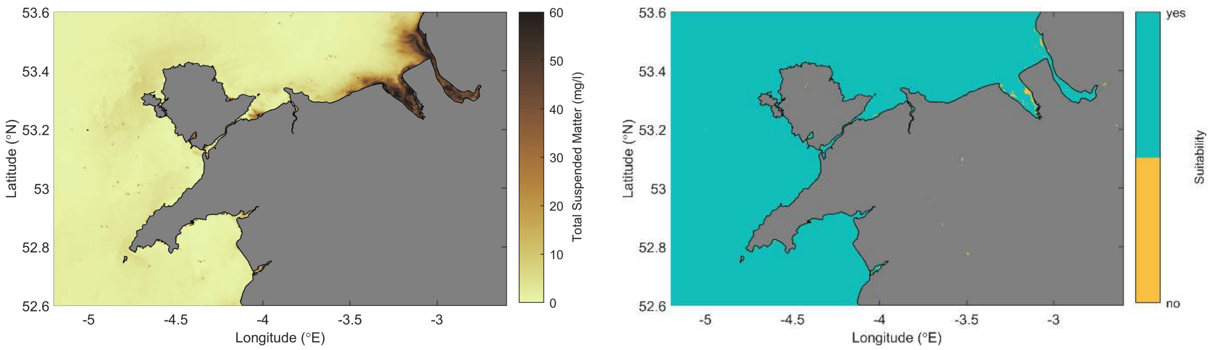

Figure A2. (left) Total suspended matter in the North Wales region. (right) Associated habitat suitability.

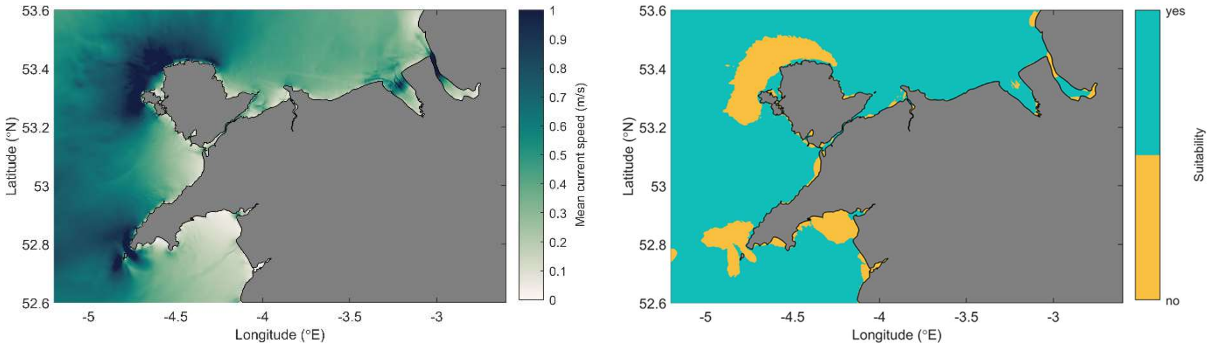

Figure A3. (left) Mean tidal current speed. (right) Associated habitat suitability.

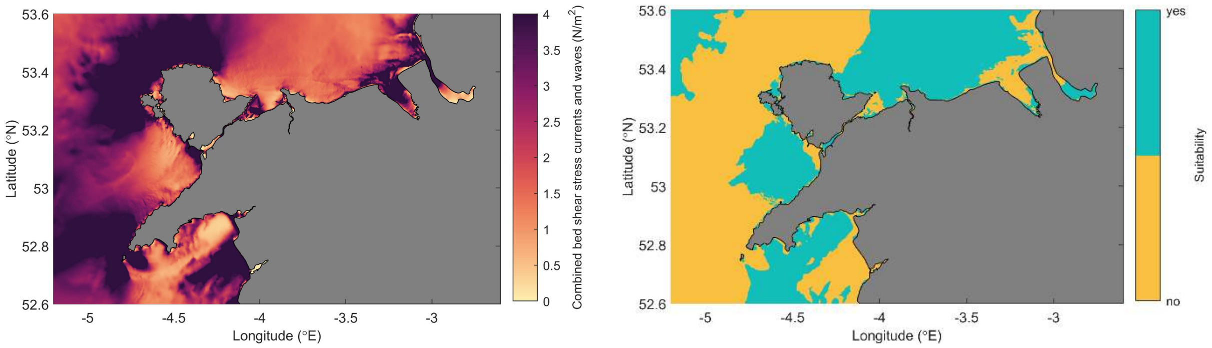

Figure A4. (left) Combined bed shear stress from currents and waves. (right) Associated habitat suitability.

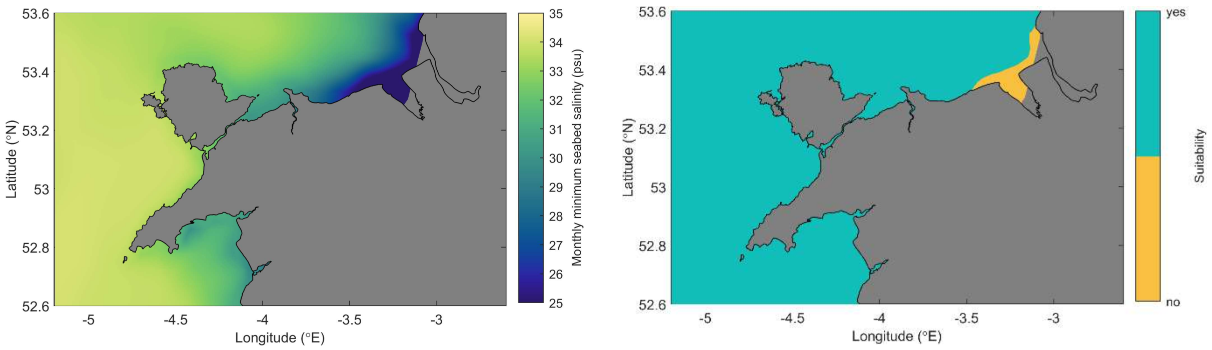

Figure A5. (left) Salinity. (right) Associated habitat suitability.

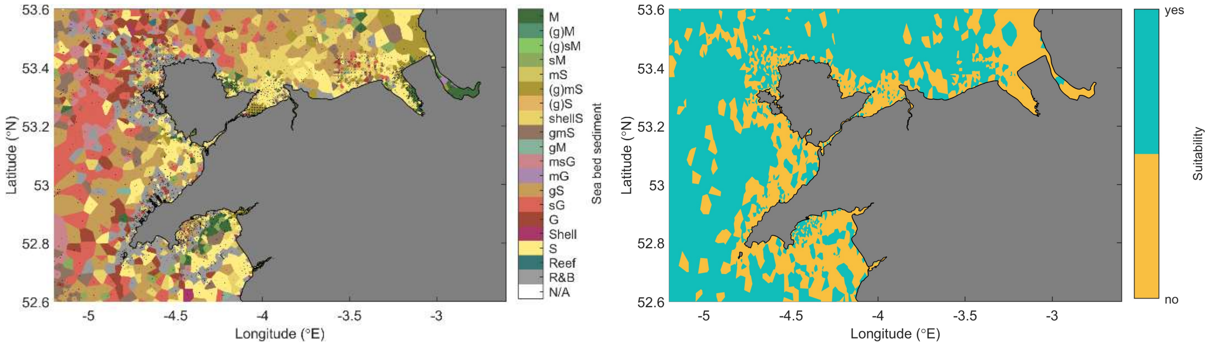

Figure A6. (left) Seabed sediment as classified by the Folk16 scale. (right) Associated habitat suitability.

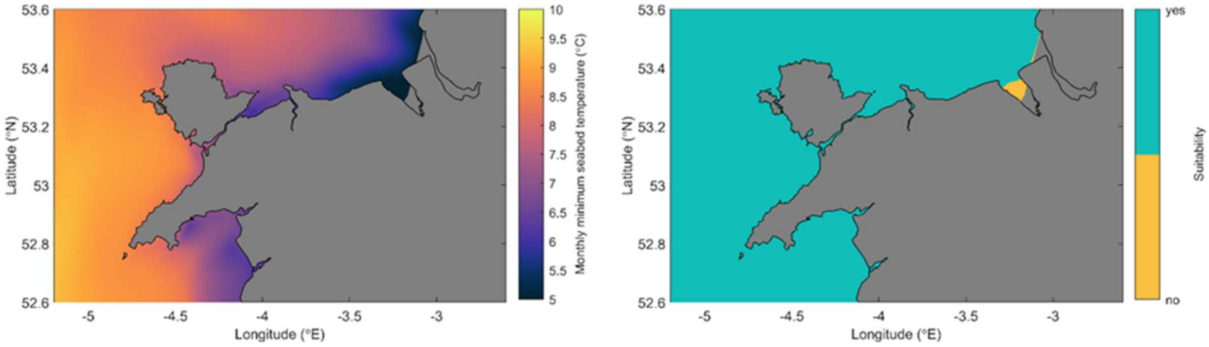

Figure A7. (left) Minimum monthly mean temperatures. (right) Associated habitat suitability.