AWAA Aquaculture Activity Assessment:

Subtidal Shellfish Aquaculture using Rafts

Report No: 720

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Contents

List of Figures

List of Tables

Crynodeb Gweithredol

Mae’r ddogfen hon yn un o gyfres o Asesiadau Gweithgareddau Dyframaethu a ddatblygwyd fel rhan o Brosiect Asesu Gweithgareddau Dyframaethu Cymru (AGDC) Cyfoeth Naturiol Cymru (CNC). Mae pob asesiad yn cyflwyno canllaw cam wrth gam ar sut i ddefnyddio'r adnoddau amrywiol a gynhyrchir gan y Prosiect AGDC er mwyn darparu gwybodaeth am y mathau o effeithiau y gallai gweithgaredd dyframaethu eu cael ar amgylchedd morol Cymru.

Mae'r asesiad hwn yn berthnasol i'r rhai sy'n asesu effeithiau posibl dyframaethu pysgod cregyn islanwol gan ddefnyddio rafftiau. Mae'r asesiad yn arwain defnyddwyr trwy broses sy'n disgrifio'r gweithgaredd dyframaethu a'r pwysau a allai godi o ganlyniad i'r gweithgaredd. Yna defnyddir astudiaeth achos i ddangos sut y gall defnyddwyr nodi sensitifrwydd y biotopau (sy'n ffurfio cydrannau o gynefinoedd) a rhywogaethau mewn lleoliad gweithgaredd dyframaeth enghreifftiol gan ddefnyddio Offeryn Mapio AGDC a Dangosfwrdd / Taenlenni Rhyngweithiadau AGDC. Yn olaf, crynhoir effeithiau posibl pob pwysau ar yr amgylchedd morol ar sail tystiolaeth a gasglwyd fel rhan o adolygiad systematig o lenyddiaeth, ac fe’i cyflwynir yng Nghronfa Ddata Tystiolaeth AGDC.

Mae'r asesiad, ynghyd ag adnoddau’r Prosiect AGDC a ddisgrifir yn yr asesiad, yn fan cychwyn defnyddiol i gasglu a datblygu gwybodaeth a thystiolaeth y gellir eu defnyddio yn ystod proses arfarnu amgylcheddol. Dylid darllen pob Asesiad Gweithgaredd Dyframaethu ar y cyd ag Adroddiad Terfynol AGDC er mwyn deall y dulliau, y tybiaethau a'r penderfyniadau sydd wedi llywio'r asesiadau a'r adnoddau a ddatblygwyd fel rhan o'r Prosiect.

Executive Summary

This document is one of a series of Aquaculture Activity Assessments developed as part of Natural Resources Wales' (NRW) Assessing Welsh Aquaculture Activities (AWAA) Project. Each assessment presents a step-by-step guide on how to use the various resources produced by the AWAA Project to provide information on the types of impacts an aquaculture activity could have on the Welsh marine environment.

This assessment is relevant to those assessing the potential impacts of undertaking subtidal shellfish aquaculture using rafts. The assessment guides users through a process describing the aquaculture activity and the pressures with the potential to occur as a result of the activity. A case study is then used to demonstrate how users can identify the sensitivity of the biotopes (which form components of habitats) and species at an example aquaculture activity location using the AWAA Mapping Tool and AWAA Dashboard / Interactions Spreadsheets. Lastly, the potential impacts of each pressure on the marine environment are summarised based on evidence collated as part of a systematic literature review, which is presented in the AWAA Evidence Database.

The assessment, together with the AWAA Project resources described in the assessment, provide a useful starting point to gather and develop information and evidence which can be used during an environmental appraisal process. Each Aquaculture Activity Assessment should be read in conjunction with the AWAA Final Report to understand the methods, assumptions and decisions that have informed the assessments and resources developed as part of the Project.

Subtidal Shellfish Aquaculture using Rafts

Introduction

This document is one of a series of Aquaculture Activity Assessments developed as part of Natural Resources Wales' (NRW) Assessing Welsh Aquaculture Activities (AWAA) Project (the Project). Each assessment provides information and guidance on the types of impacts a proposed aquaculture activity could have on the marine environment.

The Project has developed a series of resources to support the assessment of the potential impacts of different aquaculture activities. The resources are:

- The Dashboard/Interactions Spreadsheets;
- The Mapping Tool; and
- The Evidence Database.

The assessments follow a step-by-step process that guides users on how to use these resources. They demonstrate how the resources can be used as a starting point to gather information and evidence on the potential impacts occurring from an aquaculture activity.

The step-by-step process is shown in Figure 1.

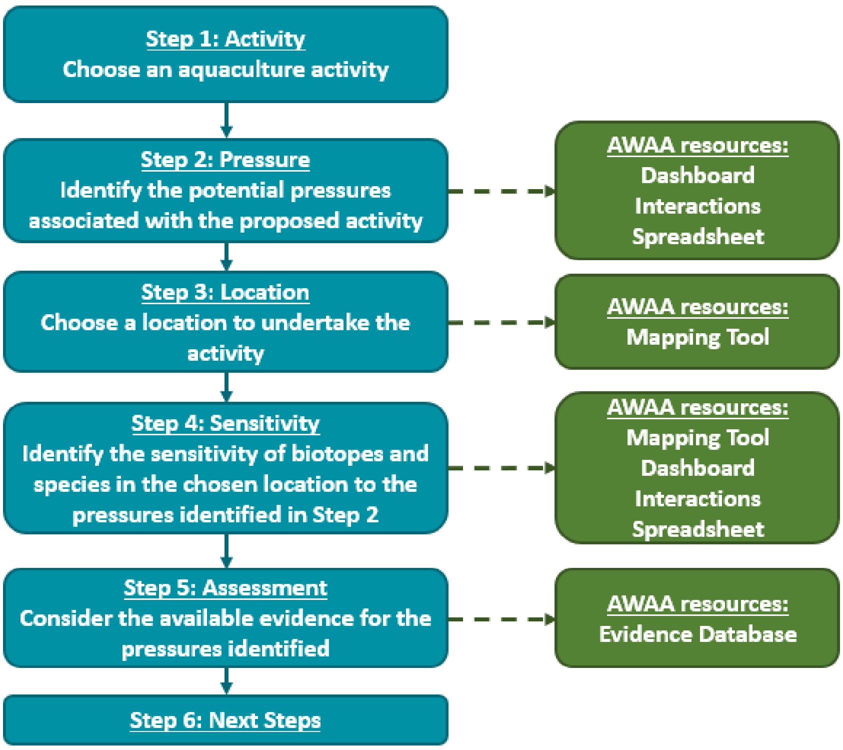

Figure 1. Flow diagram to show the step-by-step process of using the Project resources.

Aquaculture Activity Assessment General Rules

Users must remember:

- The results generated by all the AWAA resources are indicative. They are designed to provide guidance, information and evidence relating to the types of impacts that would be considered during an environmental appraisal process.
- The generic sensitivity scores, evidence summaries and mapping resources can be used as a starting point to develop a more detailed appraisal of the potential impacts the chosen aquaculture activity may have on specific marine habitats and species in an area of interest.
- The Project resources do not replace the requirement to understand the extent of the impacts a specific aquaculture activity may have on an area through, for example, consultation or by undertaking further detailed surveys to characterise an area of interest.
- Users should add specifics about the type of activity being considered within the environmental appraisal, such as its location, infrastructure, operation, species, footprint or duration etc. These factors have the potential to change the degree of exposure natural habitats and species may have to the pressures associated with the chosen aquaculture activity. This detail may require the user to consider the applicability of the indicative sensitivity values generated by the AWAA resources in terms of whether it would increase or decrease the significance of the effect of the pressures associated with the activity.
- The Project uses the sensitivity scores for biotopes (habitat communities) and species to OSPAR pressures from The Marine Evidence-based Sensitivity Assessment (MarESA) (Tyler-Walters et al., 2022) and the Natural England Mobile Species Sensitivity Assessment (2022). The sensitivity scores are indicative across a range of marine activities that could generate the pressure, including aquaculture. The pressure descriptions and benchmarks have been checked by the Project for their appropriateness to the various aquaculture activities, and comments and confidence levels are captured in the AWAA Dashboard and the Interactions Spreadsheet.

Each Aquaculture Activity Assessment should be read in conjunction with the AWAA Final Report to understand the methods, assumptions and decisions that have informed the assessments and resources developed as part of the Project, such as the AWAA Evidence Database, Dashboard, the Interactions Spreadsheets and the Mapping Tool.

Subtidal Shellfish Aquaculture using Rafts

Step 1: Activity

Choose an aquaculture activity

When planning to develop an aquaculture activity, one of the first steps is to consider the techniques to be used to grow and harvest the chosen species. The type and scale of the activity along with the methods used during collection, construction, operation and harvesting are important factors for determining the potential impacts the activity may have on the marine environment.

This assessment concerns subtidal aquaculture activity of cultivating shellfish on rafts.

Species cultivated

In the UK, mussels, oysters and scallops could be grown on rafts in subtidal shellfish aquaculture.

Mussel species include the blue mussel (*Mytilus edulis*).

Oyster species include the native European flat oyster (*Ostrea edulis*) and the non-native Pacific oyster (*Magallana gigas*, formerly known as *Crassostrea gigas*).

Scallop species include the queen scallop (*Aequipecten opercularis*) and the king scallop (*Pecten maximus*).

Infrastructure and equipment

Rafts consist of a rigid wood or metal framework or lattice which can be anywhere between $10m^2$ to $500m^2$ in size (Shellfish Industry Development Strategy, 2008). The raft can either be rigged to be near the surface of the water or on the seabed with weights or anchors used to secure the raft. If the raft is near the surface of the water, buoys or pontoons can be used to keep it afloat. Mooring lines or chains are typically attached from each corner of the raft to the anchors or weights on the seabed, with multiple raft systems connected together.

For rafts on the surface, ‘dropper’ ropes can be suspended below the rafts. The dropper ropes are on average 10m in length, but the length can vary depending on the water depth and carrying capacity of the raft. The dropper ropes are generally 12mm in diameter and are evenly spaced along the raft at 0.5m to 1m intervals to minimise the chances of tangling. A knitted sock, tubular net or mesh is normally placed around mussels on ropes or lines to reduce predation and the potential for shellfish to become detached and lost. The material of the ropes and lines varies, however, dropper ropes are often made of plastic such as polyester and the socks made of cotton.

Baskets or lantern nets can also be suspended on lines or chains below the rafts to grow scallops and oysters. They can be stacked vertically on the line to add stability to the infrastructure and to maximise space. The baskets or containers are usually made form plastic, metal or mesh.

For rafts set on the substrate, baskets are placed directly on the raft containing shellfish such as scallops or oysters.

General methods for growing and harvesting

Typically, rope culture of mussels from rafts relies on the natural settlement of mussel spat onto the ropes by their byssus threads. Spat can also be grown on separate spat collectors which are then stripped when the mussels reach 10mm, and the spat re-seeded on to the growing dropper ropes (Shellfish Industry Development Strategy, 2008). Timings for natural spatfall varies around the country but typically occurs in the spring and summer. When spatfall is poor, it is possible to purchase ropes with spat. If the lines become overcrowded when the density of mussels reaches around 1.5–2kg per metre of dropper, mussels can be moved onto new dropper ropes.

The ropes are inspected regularly to remove predators, such as starfish and crabs which can settle on the ropes when in larval form or if the droppers touch the seabed under their weight. Biofouling on the ropes is common and can be controlled through raising the ropes out of the water or relocating to areas of less settlement, however, the time of year to lift the stock or relocate needs consideration (Seafish, 2005).

When the mussels reach marketable size, usually after two to three years, each dropper is raised from the water using a winch or crane from a vessel with the mussels removed either by hand or machine. The mussels are then separated, washed and graded. Small mussels may be re-attached to the line for further growth (Seafish, 2005).

Oysters are generally obtained from hatcheries, as opposed to relying on natural spatfall. They are initially grown in fine mesh baskets or lantern nets suspended from the raft for around eight months, or once they reach 2–3cm in length. The oysters can then be placed into larger subtidal baskets or lantern nets for onward growth. Stocking densities are dependent on size with oysters graded or ‘thinned out’ every few months. As the oysters grow, stocking densities in the baskets are progressively reduced and the mesh size gradually increased. Alternatively, small oysters 2–3cm in length can be attached/glued with cement to ropes at appropriate densities for future growth and suspended in the water column from the raft (France Naissain, 2023).

Once the oysters reach marketable size after around 18 months to three years, baskets can either be detached from the longline and taken ashore or if non-detachable the stock can be managed *in situ* (Department of Primary Industries, 2021). If the oysters have been grown on ropes, they can be lifted from the water using a vessel with a winch or crane and the oysters removed either by hand or machine. The oysters are then graded and washed with any small oysters being returned to baskets or attached to ropes for further growth.

Scallop seed can be obtained from hatcheries or collected in the wild using mesh bags with a suitable settlement substrate (or cultch) to encourage the settlement of spat (Seafish, 2023). Juvenile scallops are typically placed into baskets or lantern nets to encourage growth, once large enough, they are thinned out and transferred to larger lantern nets or baskets on the seabed. Scallops can also be grown by attaching them directly to dropper lines by either drilling a hole through the ear of larger scallops and tying on, or by cementing them to the ropes. Once they reach marketable size, after three to five years the individual ropes or baskets are lifted out of the water and removed by hand.

Once the shellfish stock has been harvested from the site, onshore facilities may be required for further processing such as cleaning, grading, depurating and packing.

Subtidal Shellfish Aquaculture using Rafts

Step 2: Pressures

Identify the potential pressures associated with the proposed activity

Pressures are the mechanism through which an activity can have an effect on an ecosystem (Tyler-Walters et al., 2018). Aquaculture activities have the potential to impact the marine environment through physical, chemical and biological pressures and it is important to identify which pressures could occur from the proposed activity.

The potential pressures from growing subtidal shellfish using rafts are presented in Table 1. The Table includes a description of the pressure and how the potential pathways might occur. In line with the general rules of this assessment it is important to remember that, depending on the operation and scale etc. of the activity, the pressure pathways or significance of the pressure's effect could change.

Table 1. List of pressures, their descriptions and how they occur from the aquaculture activity. The pressures are a relevant subset of those used in MarESA (Tyler-Walters et al., 2022), unless otherwise specified.

Pressure name	Description	Pathway from aquaculture activity
Above water noise (Pressure from Natural England, 2022)	Any loud noise made onshore or offshore by construction, vehicles, vessels, tourism, mining, blasting etc.	Above water noise generated by machinery or vessels could disturb birds and marine mammals
Abrasion/disturbance of the substrate on the surface of the seabed	Physical disturbance or abrasion at the surface of the substratum in sedimentary or rocky habitats	Scouring caused by aquaculture infrastructure and anchoring to the seabed could cause abrasion
Barrier to species movement	The physical obstruction of species movements and including local movements	Infrastructure, such as lines baskets or rafts suspended in the water column may present a barrier to species movement

Pressure name	Description	Pathway from aquaculture activity
Changes in suspended solids (water clarity)	Changes in sediment, organic particulate matter and chemical concentrations can change water clarity (or turbidity)	Bivalves are filter feeder that can increase water clarity by removing suspended solids from the water, however, shellfish convert suspended solids into faeces and pseudofaeces which could affect water clarity. Construction, operation and harvesting may stir up sediment and increase turbidity
Collision ABOVE water with static or moving objects not naturally found in the marine environment (Pressure from Natural England, 2022)	The injury or mortality of biota from both static and/or moving structures	Vessels and machinery used for construction and harvesting may present a collision hazard above the water
Collision BELOW water with static or moving objects not naturally found in the marine environment	Injury or mortality from collisions of biota with both static and/or moving structures	Vessels or infrastructure such as rafts, ropes, lines or baskets suspended in the water column may present a collision hazard below the water
Genetic modification & translocation of indigenous species	Genetic modification can be either deliberate (e.g.. introductions) or a by-product of other activities (e.g. mutations)	Transplanting of indigenous species from one location to another could lead to interbreeding and alter the gene pool, which is relevant in terms of broadcast spawning shellfish species
Hydrocarbon and polycyclic aromatic hydrocarbon (PAH) contamination	Increases in the levels of these compounds compared with background concentrations	Introduced to the environment via vessel or machinery oil or fuel leaks and spills

Pressure name	**Description**	**Pathway from aquaculture activity**
Introduction of light or shading	Direct inputs of light from anthropogenic activities. Also shading from structures etc.	Infrastructure and shellfish suspended in the water column may cause shading of the seabed
Introduction of microbial pathogens (including metazoan parasites)	Untreated or insufficiently treated effluent discharges and run-off from terrestrial sources and vessels. Also, in shellfisheries where seed stock is imported, 'infected' seed could be introduced	Diseases or parasites from imported aquaculture stocks could spread quickly amongst high densities of stock and could spread to wild populations
Introduction or spread of invasive non-indigenous species (INIS)	The direct or indirect introduction of INIS	Introduction of INIS for aquaculture purposes or introduction of INIS on farmed species. Spawning from farmed stock could spread to surrounding areas
Litter	Any manufactured or processed solid material from anthropogenic activities discarded, disposed or abandoned	Rafts, ropes, lines or other infrastructure may be lost to the marine environment
Nutrient enrichment	Increased levels of the elements nitrogen, phosphorus, silicon (and iron) in the marine environment compared to background concentrations	Introduction of nutrients such as nitrogen and phosphorus to the water column and seabed through farmed species' bio-deposits
Organic enrichment	The degraded remains of dead biota and microbiota; faecal matter from marine animals; or flocculated colloidal organic matter	Introduction of organic matter through farmed species' bio-deposits

Pressure name	Description	Pathway from aquaculture activity
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	Physical disturbance of sediments where there is limited or no loss of substratum from the system	Penetration or sub-surface disturbance of the seabed from rafts, anchors or moorings
Physical change (to another seabed type)	The permanent change of one marine seabed type to another marine seabed type	Spread of aquaculture species to the surrounding habitat can lead to the establishment of bivalve reefs. In addition, aquaculture infrastructure offers an artificial substrate for colonisation
Physical change (to another sediment type)	The permanent change of one marine sediment type to another marine sediment type	Bio-sedimentary changes as a result of shell fragments or bio-deposits from shellfish reaching the seabed
Removal of non-target species	Removal of non-farmed species associated with management and harvesting activities	Ingestion of planktonic communities by filter feeders, or the removal of pests or biofouling species. Nets or lines suspended in the water column could cause entanglements
Removal of target species	The commercial exploitation of fish and shellfish stocks	Natural spatfall which would otherwise settle in the wild
Smothering and siltation rate changes ('Light' deposition)	When the natural rates of siltation are altered (increased or decreased)	Accumulation of bio-deposits and shell fragments on the seabed
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals	Increases in the levels of these compounds compared with background concentrations	The use of antifoulants to reduce unwanted settlement on infrastructure or use of pesticides

Pressure name	Description	Pathway from aquaculture activity
Transition elements and organo-metal (e.g. Tributyltin (TBT)) contamination	The increase in transition elements levels compared with background concentrations, due to their input by air or directly at sea	Introduction from antifouling compounds on infrastructure
Underwater noise changes	Increases over and above background noise levels at a particular location	Noise generated by vessels and/or machinery during construction, operation and harvesting
Visual disturbance	The disturbance of biota by anthropogenic activities (e.g. increased vessel movements)	Visual disturbance of seabirds and marine mammals as a result of vessel movement
Water flow (tidal current) changes, including sediment transport considerations	Changes in water movement associated with tidal streams, prevailing winds and ocean currents	Infrastructure and shellfish in the water column could reduce flow speeds, increase turbulence or alter water flow direction
Wave exposure changes	Local changes in wavelength, height and frequency	Infrastructure and shellfish in the water column could reduce wave action and impact local coastal processes

Subtidal Shellfish Aquaculture using Rafts

Step 3: Location

Choose a location to undertake the activity

Choosing a location to undertake the aquaculture activity will depend on a range of factors, including but limited to:

- Size of the aquaculture development;
- Accessibility of the location;
- Suitability of the environmental conditions (e.g. level of exposure to weather, tide and current);
- Suitability of the substrate;
- Land ownership;
- Location of supporting land-based infrastructure;
- Environmental considerations such as protected habitats and species in the vicinity; and
- Other users of the area.

Rafts are most often placed in areas with high levels of natural spatfall which can vary year to year. Areas sheltered from strong tidal flows and extreme wave actions with soft sediment substrates for anchoring the infrastructure are generally preferred for both rafts and baskets. Seawater temperatures of above 8°C for most of the year is usually required to facilitate growth along with salinities above 20 practical salinity units (PSU). However, areas of lower salinity can be advantageous to reduce predation from marine invertebrates such as starfish and crabs (Karayücel, 1996). Good water quality is essential, enabling a shellfish production area classification of A or B, which determines the treatment required before live bivalve molluscs may be marketed for human consumption. Disease and the presence of INIS may also influence the selection of areas.

Once a general location has been decided upon, the AWAA Mapping Tool and Dashboard, developed as part of the Project, allows the user to investigate the biotopes (which form components of habitats or protected features) and species in the surrounding area and their sensitivities to the potential pressures arising from the aquaculture activity.

An example case study at Dale in Milford Haven is provided in Step 4 that demonstrates how the AWAA Mapping Tool and Dashboard can be used if you are considering growing subtidal shellfish using rafts.

Subtidal Shellfish Aquaculture using Rafts

Step 4: Sensitivity

Identify the sensitivity of biotopes and species in the chosen location to the pressures identified in Step 2

Once you have chosen the aquaculture activity and possible location, the AWAA Mapping Tool and Dashboard can be used to investigate how sensitive biotopes and species in Welsh waters are to the pressures associated with the activity. This information can be used if undertaking an environmental appraisal.

The AWAA Mapping Tool allows the user to identify the biotopes overlapping or nearby a proposed location and therefore have the potential to be exposed to the pressures occurring from the activity. Before investigating the sensitivity of biotopes using the AWAA Mapping Tool, it is important to consider that:

- The operation and scale of the aquaculture activity might change the level of exposure of the biotopes to the pressure and hence the significance of the effect of the pressure.
- Micro-siting of the aquaculture activity can sometimes be used to reduce or avoid the pressures from impacting sensitive biotopes. However, it is also important to note that areas with no biotope records or blank areas on maps do not mean there is no exposure of biotopes to the pressure being assessed. Rather, blank areas, particularly in the subtidal, indicate there is no available survey data describing the biotopes for that location and as such further surveys may be required to characterise the area. Additionally, depending on the pressure and its zone of influence, the pressure may have the ability to affect biotopes and species at a distance from the origin of the activity, such as pressures related to pollution or sedimentation.
- The biotope data used in the AWAA Mapping Tool are a collation of surveys which have been undertaken over the last 50 years, with the majority of data collected since 1996. It is therefore important to consider whether further surveys are needed to update and/or confirm the presence of some biotopes.

Species including birds, fish, mammals and invertebrates have not been mapped by the Project as they can be exposed to the pressures being considered potentially anywhere. This reduces the value of species maps as vast areas of the sea would be highlighted as being potentially sensitive. Instead, users producing an environmental appraisal should concentrate on the other Project resources, such as the Dashboard, to understand species sensitivity to pressures, along with information such as the scale or operation of the activity and any information available on the use of the chosen area by the species of concern. It is important to acknowledge that mobile species, that form part of a site designation, should be considered wherever they occur if the proposed aquaculture location is potentially within their range.

The Dashboard provides a complete list of the biotopes currently recorded in Welsh waters. The sensitivity of both biotopes or protected species which could be exposed to the pressures at a proposed location of an aquaculture activity can be identified using the AWAA Dashboard (or Interactions Spreadsheet). In addition, the Dashboard shows the user which biotopes or species are protected within the Marine Protected Area (MPA) network or protected under Section 7 of the Environment (Wales) Act 2016.

MPA designations and protected features can be turned on or off in the AWAA Mapping Tool to allow the user to see if the proposed location of the activity and the biotopes overlap with any of these areas. However, it is important to note that not all biotopes found within a proposed location will necessarily form part of an MPA or be protected under Section 7 of the Environment (Wales) Act 2016. The user should therefore use the AWAA Dashboard (or Interactions Spreadsheet) to identify which biotopes are protected in the area of interest at the proposed activity location.

A fictional example case study focussing on Dale in Milford Haven is presented below to demonstrate how the AWAA Mapping Tool and Dashboard can be used to identify the potential sensitivity of biotopes and species in a particular area. It is important that the user considers the potential sensitivity of the biotopes and species for all of the pressures identified in Step 2 (Table 1), in their area of interest by repeating the exercise below for each pressure.

Case Study

In this example, the potential sensitivity of biotopes and species are presented for two of the pressures associated with subtidal shellfish aquaculture using rafts identified in Step 2, Table 1:

1. Abrasion/disturbance of the substrate on the surface of the seabed; and

2. Changes in suspended solids (water clarity).

The first pressure is used to demonstrate how to find out the sensitivity of biotopes in the proposed activity area. The second pressure is used to demonstrate how to find out the sensitivity of protected species in the same area.

1. Abrasion/disturbance of the substrate on the surface of the seabed

To examine the sensitivity of biotopes in the vicinity of the proposed activity, use the Mapping Tool to:

- Zoom in on Dale;
- Select the aquaculture activity ‘Subtidal Shellfish using Rafts’; and
- Select the desired pressure ‘abrasion/disturbance of the substrate on the surface of the seabed’.

For example, Figure 2 shows the sensitivity of biotopes in an area of Dale to the pressure 'abrasion/disturbance of the substrate on the surface of the seabed'. When the AWAA Mapping Tool is open the biotope codes, names, and other relevant survey information can be found by clicking on each individual biotope.

The AWAA Dashboard provides a complete list of the biotopes currently recorded in Welsh waters. To check the whether the biotopes identified from the AWAA Mapping Tool are part of an MPA or listed under Section 7 Environment (Wales) Act 2016 search the AWAA Dashboard using the following filter options:

- Select the dashboard biotope screen;
- Select the aquaculture activity 'Subtidal Shellfish using Rafts';
- Select the pressure 'abrasion/disturbance of the substrate on the surface of the seabed'; and
- Select the Welsh MPAs which overlap the proposed location.

The AWAA Dashboard will display a list of the biotopes and the designated features which the biotopes form a component. It will also indicate whether the biotopes are listed under Section 7 habitats under the Environment (Wales) Act 2016.

For the purposes of the Dale example, the biotopes considered most sensitive to abrasion/disturbance of the substrate on the surface of the seabed from subtidal shellfish aquaculture using rafts are shown in **Figure 2** The biotope with fragile species *Eunicella verrucosa* and *Pentapora foliacea* on wave-exposed circalittoral rock (CR.HCR.XFa.ByErSp.Eun) has been assessed as having a high sensitivity to abrasion/disturbance of the seabed in MarESA (Tyler-Walters et al., 2022). Eight biotopes have been assessed as having a medium sensitivity to the pressure, for example, *Laminaria hyperborea* forest with dense foliose red seaweeds on exposed upper infralittoral rock (IR.HIR.KFaR.LhypR.Ft) and Bryozoan turf and erect sponges on tide-swept circalittoral rock (CR.HCR.XFa.ByErSp). Six biotopes have been assessed as having a low level of sensitivity to abrasion/disturbance of the seabed. Please see the AWAA Final Report to understand the process of how confidence was assigned by MarESA to the sensitivity scores. There were also six biotopes which have not been assessed by MarESA. The AWAA Final Report provides further information on assessment conclusions such as any biotope sensitivity scores considered 'not relevant', 'not assessed' and having 'insufficient evidence'.

The biotopes form a component of a number of MPA features such as estuaries, reef and/or large shallow inlets and bays within the Pembrokeshire Marine Special Area of Conservation (SAC) and the Dale and South Marloes Coast Site of Special Scientific Interest (SSSI), some are also listed as Section 7 habitats.

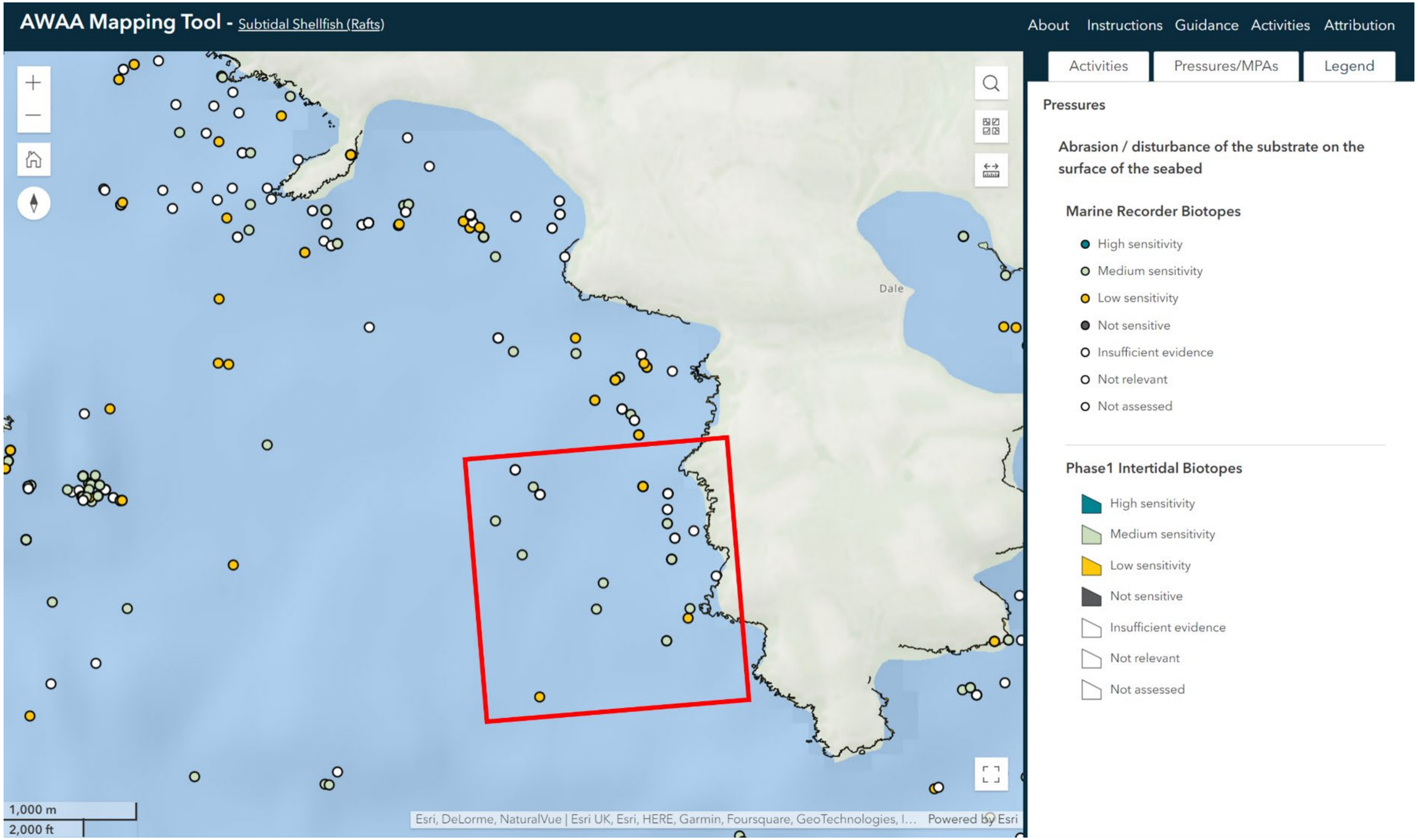

Figure 2. Use of the AWAA Mapping Tool to identify the proposed aquaculture activity location at Dale and the biotopes overlapping with the proposed area (red box).

Table 2. The sensitivity of biotopes to the pressure ‘abrasion/disturbance of the substrate on the surface of the seabed’ using the example location of Dale, Milford Haven, and the aquaculture activity of growing subtidal shellfish on rafts. Ordered from High to Low sensitivity. The Table also indicates if a biotope forms part of a Section 7 Environment (Wales) Act 2016 habitat and/or which MPAs and features the biotopes are part of.

Biotope name	Biotope code	Sensitivity [confidence]	Section 7 habitats which include the biotope	MPAs where the biotope is protected	MPA features which include the biotope
Eunicella verrucosa and *Pentapora foliacea* on wave-exposed circalittoral rock	CR.HCR.XFa.ByErSp.Eun	High [Medium conf.]	Fragile sponge and anthozoan communities on subtidal rocky habitats	Pembrokeshire Marine SAC	Large Shallow Inlets and Bays; Reef
Laminaria hyperborea forest with a faunal cushion (sponges and polyclinids) and foliose red seaweeds on very exposed upper infralittoral rock	IR.HIR.KFaR.LhypFa	Medium [High conf.]	Not Section 7	Pembrokeshire Marine SAC; Dale and South Marloes Coast SSSI	Large Shallow Inlets and Bays; Reef; Exposed rock
Laminaria hyperborea forest with dense foliose red seaweeds on exposed upper infralittoral rock	IR.HIR.KFaR.LhypR.Ft	Medium [High conf.]	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Laminaria hyperborea park and foliose red seaweeds on moderately exposed lower infralittoral rock	IR.MIR.KR.Lhyp.Pk	Medium [High conf.]	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Laminaria hyperborea park with dense foliose red seaweeds on exposed lower infralittoral rock	IR.HIR.KFaR.LhypR.Pk	Medium [High conf.]	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef

Biotope name	Biotope code	Sensitivity [confidence]	Section 7 habitats which include the biotope	MPAs where the biotope is protected	MPA features which include the biotope
Bryozoan turf and erect sponges on tide-swept circalittoral rock	CR.HCR.XFa.ByErSp	Medium [Medium conf.]	Fragile sponge and anthozoan communities on subtidal rocky habitats	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Laminaria hyperborea park with hydroids, bryozoans and sponges on tide-swept lower infralittoral rock	IR.MIR.KR.LhypT.Pk	Medium [Medium conf.]	Tide-swept channels	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Mixed turf of bryozoans and erect sponges with *Dysidia fragilis* and *Actinothoe sphyrodeta* on tide-swept wave-exposed circalittoral rock	CR.HCR.XFa.ByErSp.DysAct	Medium [Medium conf.]	Fragile sponge and anthozoan communities on subtidal rocky habitats	Pembrokeshire Marine SAC	Large Shallow Inlets and Bays; Reef
Urticina felina and sand-tolerant fauna on sand-scoured or covered circalittoral rock	CR.MCR.EcCr.UrtScr	Medium [Medium conf.]	Not Section 7	Pembrokeshire Marine SAC	Reef
Pomatoceros triqueter, *Balanus crenatus* and bryozoan crusts on mobile circalittoral cobbles and pebbles	ECR.PomByC	Low [High conf.]	Subtidal sands and gravels	Not designated as part of an MPA	NA
Spirobranchus triqueter with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles	SS.SCS.CCS.SpiB	Low [High conf.]	Subtidal sands and gravels	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef

Biotope name	Biotope code	Sensitivity [confidence]	Section 7 habitats which include the biotope	MPAs where the biotope is protected	MPA features which include the biotope
Alaria esculenta and *Laminaria digitata* on exposed sublittoral fringe bedrock	IR.HIR.KFaR. Ala.Ldig	Low [Low conf.]	Not Section 7	Pembrokeshire Marine SAC; Dale and South Marloes Coast SSSI	Estuaries; Large Shallow Inlets and Bays; Reef; Exposed rock; Moderately exposed rock
Flustra foliacea on slightly scoured silty circalittoral rock	CR.MCR.EcCr .FaAlCr.Flu	Low [Medium conf.]	Not Section 7	Pembrokeshire Marine SAC	Reef
Foliose red seaweeds on exposed lower infralittoral rock	IR.HIR.KFaR. FoR	Low [Medium conf.]	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Foliose red seaweeds with dense *Dictyota dichotoma* and/or *Dictyopteris membranacea* on exposed lower infralittoral rock	IR.HIR.KFaR. FoR.Dic	Low [Medium conf.]	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Circalittoral coarse sediment	SS.SCS.CCS	Not Assessed	Subtidal sands and gravels	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef; Sandbanks which are slightly covered by seawater all the time
Infralittoral coarse sediment	SS.SCS.ICS	Not Assessed	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Mixed faunal turf communities	CR.HCR.XFa	Not Assessed	Not Section 7	Pembrokeshire Marine SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Sublittoral coarse sediment (unstable cobbles and pebbles, gravels and coarse sands)	SS.SCS	Not Assessed	Subtidal sands and gravels	Not designated as part of an MPA	NA
Sublittoral sands and muddy sands	SS.SSa	Not Assessed	Subtidal sands and gravels	Not designated as part of an MPA	NA
Very tide-swept faunal communities	CR.HCR.FaT	Not Assessed	Tide-swept channels	Pembrokeshire Marine SAC	Large Shallow Inlets and Bays; Reef

2. Changes in suspended solids (water clarity)

The sensitivity of protected species which could overlap with the proposed location of an aquaculture activity can be identified using the species AWAA Dashboard using the following filter options:

- Select the dashboard species screen;
- Select the aquaculture activity ‘Subtidal Shellfish using Rafts’;
- Select the pressure ‘changes in suspended solids (water clarity); and
- Select the MPAs which overlap or are adjacent to the proposed location and/or Section 7 species.

The AWAA Mapping Tool can be used to identify the MPAs which overlap with or are close to the proposed aquaculture site in the Dale example case study. The AWAA Dashboard can then be used to ascertain the protected species within the MPA or on the Section 7 list and their sensitivity to the pressure being considered. The MPAs are shown in **Table 3** and include:

- Pembrokeshire Marine SAC
- Cleddau Rivers SAC;
- Skomer, Skokholm and the Seas off Pembrokeshire Special Protection Area (SPA); and
- Dale And South Marloes Coast SSSI.

The majority of bird species protected in the Skomer, Skokholm and the Seas off Pembrokeshire SPA, including Guillemot, Kittiwake, Lesser Black-Backed Gull, Puffin and Razorbill, have been assessed as having a medium sensitivity to changes in suspended solids (water clarity) in the Natural England (2022) sensitivity assessment. Manx Shearwater and Storm Petrel, protected in the Skomer, Skokholm and the Seas off Pembrokeshire SPA, and Allis Shad and Twaite Shad, protected in the Pembrokeshire Marine SAC, have been assessed as having a low level of sensitivity to the pressure. Please see the AWAA Final Report to understand the process of how confidence was assigned by Natural England to the sensitivity scores. The Natural England sensitivity assessment found no direct evidence of the impacts of changes in suspended solids on River or Sea Lamprey or Otter, and the pressure was considered not to be relevant to Grey Seal. Red seaweed species, features of the Dale and South Marloes Coast SSSI and listed on Section 7, were not assessed by MarESA (Tyler-Walters et al., 2022). The AWAA Final Report provides further information on assessment conclusions such as species' sensitivity scores considered ‘not relevant’, ‘not assessed’ and having ‘insufficient evidence’.

To understand the potential impact of the pressure in the example case study location of Dale, it is important to understand the potential use of the area by the species concerned.

Table 3. The sensitivity of designated species features to the pressure 'changes in suspended solids (water clarity)' using the example location of Dale, Milford Haven, and the aquaculture activity of growing subtidal shellfish using rafts. Ordered from High to Low sensitivity. The Table also indicates if a species is a Section 7 Environment (Wales) Act 2016 species and/or which MPAs the species is a designated feature of.

Common Name	Scientific Name	Sensitivity [confidence]	Section 7 species (Y/N)	MPAs where species are part of the site designation
Guillemot (breeding)	*Uria aalge*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Guillemot (non-breeding)	*Uria aalge*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Kittiwake (breeding)	*Rissa tridactyla*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Kittiwake (non-breeding)	*Rissa tridactyla*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Lesser black-backed gull (breeding)	*Larus fuscus*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Lesser black-backed gull (non-breeding)	*Larus fuscus*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Puffin (breeding)	*Fratercula arctica*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Puffin (non-breeding)	*Fratercula arctica*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Razorbill (breeding)	*Alca torda*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Razorbill (non-breeding)	*Alca torda*	Medium [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Manx shearwater (breeding)	*Puffinus puffinus*	Low [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Storm petrel (breeding)	*Hydrobates pelagicus*	Low [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Storm petrel (non-breeding)	*Hydrobates pelagicus*	Low [Low conf.]	No	Skomer, Skokholm and the Seas off Pembrokeshire SPA
Allis shad	*Alosa alosa*	Low [Medium conf.]	Yes	Pembrokeshire Marine SAC

Common Name	Scientific Name	Sensitivity [confidence]	Section 7 species (Y/N)	MPAs where species are part of the site designation
Twaite shad	*Alosa fallax*	Low [Medium conf.]	Yes	Pembrokeshire Marine SAC
Otter	*Lutra lutra*	No direct evidence	Yes	Pembrokeshire Marine SAC
River lamprey	*Lampetra fluviatilis*	No direct evidence	Yes	Pembrokeshire Marine SAC; Cleddau Rivers SAC
Sea lamprey	*Petromyzon marinus*	No direct evidence	Yes	Pembrokeshire Marine SAC; Cleddau Rivers SAC
Grey seal	*Halichoerus grypus*	Not relevant	No	Pembrokeshire Marine SAC; Dale & South Marloes Coast SSSI
Grey seal	*Halichoerus grypus*	Not relevant	No	Dale & South Marloes Coast
A red seaweed	*Cruoria cruoriaeformis*	Not assessed	Yes	Dale & South Marloes Coast SSSI
A red seaweed	*Dermocorynus montagnei*	Not assessed	Yes	Dale & South Marloes Coast SSSI
A red seaweed	*Gigartina pistillata*	Not assessed	No	Dale & South Marloes Coast SSSI

Subtidal Shellfish Aquaculture using Rafts

Step 5: Assessment

Consider the available evidence for the pressures identified

Once the habitats and species in the vicinity of the proposed activity have been identified and their sensitivities determined, it may be necessary to consider the potential impacts the pressures may have alone and in combination in an environmental appraisal process.

As part of the Project, an extensive literature review was undertaken to compile an Evidence Database. The AWAA Evidence Database provides the user with the available evidence to inform an environmental appraisal by bringing together the current evidence on the pressures generated by different aquaculture activities and the impacts they could have on habitats and species.

The AWAA Evidence Database was compiled over the duration of the Project and captures the existing knowledge at the time of writing. There is the potential that new evidence becomes available following publication, therefore, the user is encouraged to conduct a search for any new evidence, particularly for those pressures for which there is little or no direct evidence identified within the AWAA Evidence Database.

Any interpretation of the evidence and the sensitivity of biotopes and species will be dependent on a number of factors including the operation and scale of the aquaculture activity. In an environmental assessment, the available evidence should therefore be considered in the context of the proposal and confidence in the evidence, particularly where contrasting information on the impacts is available. Where no evidence is available on the impacts of a pressure occurring from an aquaculture activity, the user may have to consider the applicability of evidence from other activities that could generate similar pressures and clearly state what assumptions have been made along with any associated limitations.

Summaries of the evidence sources identified in the AWAA Evidence Database for each of the pressures relating to subtidal shellfish aquaculture using rafts identified in Step 2 (Table 1) are provided below.

The evidence summaries for the pressures used in the Dale case study example in Step 4 are provided below in sections 2 and 4.

1. Above water noise

Although no evidence was found in the scientific literature for this pressure with respect to subtidal shellfish aquaculture using rafts, above water noise is expected to occur during construction, maintenance and harvesting. Above water noise has the potential to disturb bird or marine mammal species in the vicinity of the activity.

2. Abrasion/disturbance of the substrate on the surface of the seabed

Abrasion, scouring or disturbance of the seabed is likely to occur during the placement of rafts on the seabed or from the use of anchors/weights on the seabed to secure floating infrastructure.

Shellfish farms sited directly over sensitive habitats, such as seagrass and maerl beds, have the potential to lead to the physical loss of these habitats through scouring from anchoring or mooring systems. However, although the pressure from shellfish grown on rafts is acknowledged in the literature (McKindsey et al., 2011), the impact of these structures is not widely investigated. Scouring impacts are expected to be relatively localised, with small-scale farming and innovative mooring technologies potentially limiting the impacts of abrasion.

3. Barrier to species movement

In general, subtidal aquaculture infrastructure has the potential to exclude species such as seals or cetaceans from habitats. There is mixed information in the literature regarding potential cetacean or seal avoidance of aquaculture infrastructure and operations.

Some studies report that aquaculture has no impact, for example, in Ireland, seal abundance was not shown to be impacted by the presence of suspended mussel culture (Roycroft et al., 2004). While other investigations have shown marine mammals being attracted to aquaculture sites (Lopez and Methion, 2017).

However, some reports indicate that cetaceans have been shown to avoid areas of aquaculture which can act as a barrier to their foraging grounds (Markowitz et al., 2004; Watson-Capps and Mann, 2005; Pearson et al., 2009; Andres et al., 2021). Therefore, subtidal shellfish farms may have the potential to displace some marine mammal species.

The variation in the literature likely reflects the difference in the scale and specific set up of the shellfish farms and also behavioural differences between marine mammals (Clement et al., 2013; Lopez and Methion, 2017). Overall, impacts will depend on scale of the activity, with the barrier to species movement increasing with the scale of the aquaculture activity. It will also depend on the species present in the area of interest as some have the potential to be attracted to aquaculture sites and some will be more sensitive than others (Clement et al., 2013).

4. Changes in suspended solids (water clarity)

Construction and the operation (such as dredging for seed stock) of subtidal shellfish farms have the potential to increase turbidity of the water column due disturbance of the seabed leading to resuspension of sediments. Suspended sediments in the water column have the potential to reduce the visibility of marine predators such as marine mammals, fish and diving or surface feeding seabirds, reduce light penetration, clog filtration mechanisms of filter feeders or lead to behavioural alterations (Todd et al., 2015; Ortega et al., 2020). However, increases in suspended solids would likely be short-term and relatively localised.

As filter-feeders, most cultivated shellfish species have the potential to reduce suspended solids and increase water clarity over time. Rather than having a negative impact this is considered positive in areas of increased nutrient or organic loading. In some cases, subtidal shellfish culture has been used in conjunction with fish cages to mitigate against the environmental impacts of the fish aquaculture activity (Reid et al., 2010). Whilst shellfish can improve water clarity, shellfish convert these suspended solids into faeces and pseudofaeces which are deposited to the seafloor (see ‘organic enrichment’) (Huntington et al., 2006; Gallardi et al., 2014; Watenberg et al., 2017).

Shellfish can reduce ‘suspended solids’ in the form of phytoplankton and zooplankton by their filter-feeding, which in turn can impact prey abundance for species in nearby areas or the recruitment of benthic species that have planktonic life history stages (Leguerrier et al., 2004; International Council for the Exploration of the Sea (ICES), 2020). In terms of this assessment however, these impacts have been categorised under the ‘removal of non-target species’ pressure.

5. Collision ABOVE water with static or moving objects

There is the potential for species to collide with vessels above the water during construction, operation and harvesting. However, no evidence was found in the scientific literature relating to the collision of species above water with subtidal shellfish aquaculture using rafts. It is likely that any such instances would be relatively rare and unlikely to cause a significant impact.

6. Collision BELOW water with static or moving objects

There is the potential for species to collide with infrastructure or operational vessels during the cultivation, harvesting or collection of seed stock, however, no evidence was found for this pressure in the scientific literature. It is likely that any such instances would be relatively rare and unlikely to cause a significant impact.

7. Genetic modification & translocation of indigenous species

A global review acknowledged that bivalve aquaculture could alter population genetic structure of wild populations (Beninger and Shumway, 2018), however, there is limited understanding on the impacts of this on habitats and species. The MarESA assessment suggested the transplanting of indigenous species from one location to another for aquaculture purposes could lead to interbreeding with local populations and potentially alter the gene pool, which could be relevant in terms of shellfish species broadcast spawning (Beninger and Shumway, 2018). Brenner et al (2014) found evidence of hybridisation between oyster species in southern Europe, stating that this process is unpredictable and can lead to a loss of genetic diversity or the breakdown of co-adapted gene complexes, resulting in a poor commercial product.

8. Hydrocarbon and PAH contamination

No evidence was found in the scientific literature relating to hydrocarbon or PAH contamination from subtidal shellfish aquaculture using rafts.

However, it is expected that this pressure in the form of fuel or oil leaks and spills could occur through the use of vessels during construction and operational processes.

9. Introduction of light or shading

Shading of the seabed could occur from any off-bottom aquaculture infrastructure. Shading has the potential to lead to a reduction in photosynthesis and growth rate in algal species and can have a negative impact on invertebrate species which rely on light as a cue for spawning. Shading under suspended oyster culture has been found to decrease the biomass and primary production of seagrass (Skinner et al., 2014) with the level of impact dependent on the stocking density of oysters and the age of the farm. Mussel farming has also been shown to decrease primary productivity and microbial plankton metabolism (Frojan et al., 2018). It is likely that the impact of shading will be localised and could have detrimental impacts on some sensitive species or habitats. The shading of benthic invertebrates is unlikely to be relevant, except where it may interfere with spawning cues (Scottish Government, 2020). This risk of this pressure will increase as the size of the farm increases and large areas of the water's surface may be occupied with rafts and concentrated dropper lines.

10. Introduction of microbial pathogens (including metazoan parasites)

Diseases have caused the mass mortality of bivalve stocks in Europe. Common diseases in oysters in UK waters include Ostreid herpesvirus (OsHV-1), Bonamiosis (caused by a group of parasites of the genus *Bonamia*), and diseases from *Vibrio* bacteria.

A review by Bouwmeester et al. (2020) highlighted that the nature of aquaculture makes farmed species particularly prone to disease outbreaks through (1) the translocation and introduction of aquaculture stocks which can lead to the co-introduction of pathogens and parasites, (2) the often low genetic diversity of aquaculture stocks which increases the susceptibility of hosts and the virulence of pathogens, and (3) the stocking densities in aquaculture settings provide ideal conditions for pathogens and parasites to thrive as they are often much higher than would be found in natural environments.

It is recognised that diseases in aquaculture stocks have the potential to infect wild populations and could be spread via the water column (Wilkie et al., 2013; Bouwmeester et al. 2020; Ticina et al., 2020). A study undertaken in eastern Australia on wild and farmed Sydney rock oyster (*Saccostrea glomerata*) showed that disease of aquaculture stocks infected wild populations, however, wild populations appeared to be less negatively affected than cultured (Wilkie et al., 2013). The use of plastics within aquaculture baskets or ropes have the potential to act as a vector for higher abundances of pathogens and bacteria than the surrounding water, such as genera *Vibrio* (Sun et al., 2020; Mohsen et al., 2022). However, there is no evidence on the ability of these pathogens to transfer across to and infect aquaculture species.

In the UK, there is the potential that wild populations of native oyster and mussel species can become infected by diseases from shellfish aquaculture. In extreme circumstances, if infections in wild populations lead to mass mortality, this could have wider, indirect impacts on a range of species reliant on shellfish.

Parasites occur naturally in the marine environment and can infect species used in aquaculture. Compared to the natural environment, aquaculture facilities have high densities of stock which can facilitate parasites to spread quickly and easily. Parasites have the potential to spread from aquaculture sites and infect nearby wild populations or increase the parasitic load within wild populations where the parasites may already exist (Beninger and Shumway, 2018). In addition, stock imported for cultivation could harbour new and potentially non-indigenous parasites. Costello at al. (2021) listed different parasites which have been introduced as a result of bivalve aquaculture. This includes, for example, the parasitic red worm *Mytilicola orientalis* which has spread from aquaculture of Pacific oysters to native blue mussels and other bivalve species; the spreading of fungus from Pacific oyster shells; the spreading of the protistan *Haplosporidium nelson* in the US from infected Pacific oyster spat which has now spread to native oyster *Crassostrea virginica*. They do, however, go on to state that more work is needed to fully understand how these infection vectors may relate to the marine ecosystem as a whole.

It is also possible that parasitic species imported via aquaculture may harbour pathogens that could spread and affect parasitic species. For example, Longshaw et al. (2012) studied pea crabs (*Pinnotheres pisum*) in the mantle cavities of blue mussels. They found that from a total of 266 pea crabs from around the English coastline, 184 were infected with a number of pathogens and parasites including: an intranuclear bacilliform virus; an intracytoplasmic microsporidian infection; a myophilic microsporidian infection; the isopod *Pinnotherion vermiforme*; and a low-level nematode infection.

11. Introduction or spread of INIS

Aquaculture can lead to the spread of INIS through a variety of different pathways, including the intentional introduction of INIS as the target aquaculture species and the accidental introduction of 'hitchhiking' INIS mixed in with or colonising the shells of aquaculture species and equipment. For example, the introduction of the INIS Pacific oyster for aquaculture has led to the spread of the species from the points of introduction. A study by Zwerschke et al. (2018) in Ireland found that in 37 sites where Pacific oysters were introduced for aquaculture, 20 of the sites had established wild populations.

It has been suggested that INIS such as wireweed (*Sargassum muticum*) and leathery sea squirt (*Styela clava*) have been accidentally introduced as a result of Pacific oyster aquaculture in the UK (Macleod et al., 2016, Huntington et al., 2006) and the Japanese oyster drill (*Ocinebrellus inornatus*) in Europe and North America (Lützen et al., 2012). In a global review of invasive macroalgae introductions, 54% of introductions were derived from aquaculture either through macroalgae cultivation or indirectly through imports for shellfish farming (Williams and Smith, 2007).

Aquaculture which adds infrastructure to the environment could enhance INIS establishment due to their typically opportunistic nature and ability to thrive on artificial substrates, such as anchors (McKindsey et al., 2011).

The impacts of INIS will depend on the particular INIS, the habitat they have been introduced to, and their ability to become established (Herbert et al., 2016). INIS introduced via aquaculture could cause a range of impacts including:

- Competition with native species for food and space;
- Predation on native species;
- Introduction of pathogens;
- Smothering;
- Modifying currents and changing sedimentation; and
- Changing habitat type.

Studies suggest that the spread of INIS from aquaculture can have both positive and negative effects on habitats and species. Pacific oysters have led to unfavourable conditions of a range of sedimentary and rock MPA features where densities of oysters are high or reefs are forming. Tillin et al. (2020) suggested that fish species including plaice, sole, skates and rays could be impacted where Pacific oysters colonise sheltered soft sediments and reduce availability of benthic food supply, however, they found no evidence of such impacts. Pacific oysters competing for space and food is a concern for other filter feeders or biogenic reef forming organisms such as mussels, native oysters and *Sabellaria alveolata*. However, evidence suggests that Pacific oyster beds could increase settlement opportunities for mussels and other species which require hard substrates in order to colonise (Fey et al., 2010; Tillin et al., 2020). Oyster beds increase habitat heterogeneity and therefore promote biodiversity and lead to stabilisation of sediments over long time scales (Troost, 2010), although this may lead to changes to the original habitat designation.

12. Litter

In general, aquaculture activities are recognised as a potential pathway for the introduction of marine litter. Abandoned or lost gear such as netting, raft material, ropes and line fragments can pose a significant threat, especially for seabirds (Massetti et al., 2021). Skirtun et al. (2022) highlighted the key risks posed to wildlife from marine plastic pollution includes entrapment and entanglement of marine organisms; ingestion of macro- and micro-plastic by animals; transfer of harmful chemicals to wildlife; transport of non-indigenous species; and smothering of marine fauna.

Macro-plastic pollution in the form of lost or abandoned gear from aquaculture can impact marine biodiversity by altering or modifying species assemblages (Werner et al., 2016). This is primarily through the introduction of foreign species transported via floating plastic debris, or sunken litter that forms new artificial habitats, both of which threaten native biodiversity.

13. Nutrient enrichment

Shellfish have the potential to provide an ecosystem service by acting as a bioremediator and limiting nutrient enrichment (ICES, 2020). However, shellfish aquaculture operations have the potential to increase nitrogen and phosphorus in the water column and at the seabed from release of faeces and pseudofaeces (Bouwman et al., 2011). A review by

Burkholder and Shumway (2011) on the impact of eutrophication from shellfish aquaculture found that only 7% of the systems examined showed severe eutrophication impact related to the aquaculture operations. The locations with the worst impacts of eutrophication were in poorly flushed, shallow lagoons (Beninger and Shumway, 2018). It is important to note that bivalve, crustacean and gastropod aquaculture is increasing, with global models suggesting that nutrient release could grow from 0.4 to up to 1.7 million tonnes for nitrogen and from 0.01 to 0.3 million tonnes of phosphorus between 2006 and 2050 (Bouwman et al., 2011).

Eutrophication due to aquaculture has been correlated with increased growth of epiphytic algae (in particular filamentous), drift algae and phytoplankton which has the potential to compete with other species, particularly seagrass, for nutrients or light (Den Hartog, 1987). Loss of the seagrass exposes the seabed to wave action causing resuspension, which further increases turbidity, thereby creating one of several positive feedback loops of eutrophication, hampering the remaining benthic flora.

Nutrient enrichment may also occur indirectly from organic enrichment where accumulated biodeposits plus short-term hypoxic periods can lead to active mineralisation of sedimentary organic matter, inducing production of ammonia and sulphur (Bouchet and Sauriau, 2008).

14. Organic enrichment

Organic enrichment is well documented to occur through biodeposition of shellfish faeces which can lead to a change in sediment quality (Huntington et al., 2006; Cao et al., 2007; Bouchet and Sauriau 2008; McKindsey et al., 2011; Grant et al., 2012; Forde et al., 2015; ICES, 2020). Biodeposition from shellfish can increase benthic organic loading which can affect biochemical processes in the sediments and lead to deoxygenation, and changes in the pH and redox potentials in the sediments. For example, under mussel rope culture in Italy, organic enrichment led to highly reduced sediments in both summer and winter months (Nizzoli et al., 2005) which in turn can change the composition of benthic infaunal communities (McKindsey et al., 2011). Ysebaert et al. (2009) found that biodeposition from mussel culture changed species composition from species which are typically present in sandy environments to opportunistic species that are typically present in organically enriched sediments. Wisehart et al. (2007) found that reduced sediments, as a result of organic enrichment, have been observed around longline shellfish aquaculture sites in the United States as a result of faeces and pseudofaeces deposits. The authors stated that low redox values may change the microbial community, increase silt and lead to hypoxia and sulphides in the sediment which are toxic to species such as seagrass seedlings.

The amount of biodeposits produced and the rate at which they settle is highly variable and dependent on bivalve species, diet and size. The volume of biodeposition can be high, with Cao et al. (2007) stating that in China, 420,000 oysters produced around 16 tonnes of excreta during a nine-month culture. Most studies on organic enrichment of the seabed from shellfish farming have concluded that the effect is often small, localised, and much less than that caused by finfish farming (Crawford et al., 2003; Callier et al., 2006). However, the level of organic enrichment will depend on the size of the activity and the local coastal processes.

15. Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion

No studies were found that investigated the impacts of seabed penetration from static aquaculture infrastructure. However, penetration and/or disturbance of the substrate below the surface of the seabed could result from infrastructure such as rafts being fixed to the seabed or moorings, anchors or screw piles being driven into the seabed. This disturbance has the potential to lead to direct mortality or localised displacement of infaunal species with the amount of impact dependent on the scale of the activity.

16. Physical change (to another seabed type)

Aquaculture infrastructure could potentially change a flat bottom space into an area which offers a three-dimensional artificial habitat for species to colonise and increase local biodiversity (Craeymeersch et al., 2013; Glenn et al., 2020; ICES, 2020). The subtidal rafts, weights or anchors provide artificial structures for a range of benthic organisms including seaweeds, tunicates, razor clams and crabs (Wood et al., 2017) to live on.

Once the aquaculture activity ceases, the habitat has the potential to change back to its original state. However, the potential spread of shellfish from aquaculture sites may lead to the establishment of new mussel or oyster reefs and hence permanently change the seabed type from a soft-bottom to hard-bottom substrate. Oysters and mussels are a bioengineering species with the potential to transform mudflat areas they colonise into a hard-bottomed seabed. This in turn can lead to displacement or smothering of soft-sediment communities and a shift hard-bottom communities (Huntington et al., 2006; Mortensen et al., 2017; ICES, 2020).

17. Physical change (to another sediment type)

Large amounts of biodeposits or shell fragments from shellfish aquaculture have the potential to change sediment type underneath or in the vicinity of the aquaculture plots (Wilding and Nickell, 2013; Ahmed and Solomon, 2016). Beadman et al. (2004) described shellfish such as mussels creating a secondary habitat comprised of accumulated sediment faeces, pseudofaeces and shell debris. Shell debris has a low level of degradability which can become integrated into the existing sediment and modify its structure and biogeochemical processes (Casado-Coy et al., 2022). High levels of shell material in the sediments have the potential to influence the macrobenthos underneath ‘off bottom’ aquaculture sites. Wilding and Nickell (2013) showed macrofaunal abundance increased under Scottish mussel farms due to shell material compared to control sites, but species diversity remained the same. Changes in the species occupying areas beneath mussel farms with deposited shell material has also been reported in New Zealand (Wong and O’Shea, 2011). Accumulation of shell material has the potential to alter macrofaunal communities and provide habitat for fouling and marine organisms which require a hard substrate to settle (Wong and O’Shea, 2011; ICES, 2020).

However, evidence suggests that any changes to the species community, as a result of shell debris is likely dependent on other factors such as organic matter and existing grain size of the sediment and hydrodynamics of the area (Casado-Coy et al., 2022). Sediment grain composition could also change due to disturbance of the sediments around subtidal aquaculture which may also lead to the loss of fine particles and subsequently change infaunal community composition (ICES, 2020).

18. Removal of non-target species

There are very few reports of entanglement of marine mammals or birds with subtidal aquaculture, however, reports suggest that birds, turtles, small cetaceans such as porpoises and even large species such as whales can become entangled (Baker et al., 2005; Young, 2015). Subtidal raft infrastructure has the potential risk of entanglement if loose lines or ropes are suspended in the water column (Methion and Lopez, 2019; Clement, et al., 2013). Grow out ropes for shellfish are expected to cause less of an entanglement risk as they are generally thicker and more tightly anchored and more tightly tensioned than lines attached to anchors or marker buoys. Anti-predator netting can also be used to deter birds from shellfish aquaculture sites, however, studies suggest that thin twine and large mesh sizes are likely to cause bird entanglement (Varennes, et al., 2013).

Filter-feeding shellfish, such as mussels, oysters and clams, ingest phytoplankton and zooplankton from the surrounding water column. Studies examining the stomach contents of mussels and other bivalves found that they can ingest copepods and barnacle larvae (Lehane and Davenport, 2006) as well as other bivalve larvae, tintinnids, gastropod larvae and invertebrate eggs (Peharda et al., 2012). Peharda et al. (2012) state that numbers of bivalve larvae in *Mytilus galloprovincialis* stomach were the highest found and show that mussels can impact the availability of natural spat. Therefore, the removal of zooplankton in the form of invertebrate larvae from large-scale bivalve aquaculture has the potential to affect local populations of wild indigenous species (Gendron et al., 2003; Lehane and Davenport, 2006; Peharda et al., 2012).

It was suggested by Smith et al. (2018) that cultured oysters may benefit seagrass species by feeding on epiphytic diatoms and epiphyte propagules before they can settle on the seagrass. This in turn could reduce epiphyte loads and influence subsequent faunal settlement.

Species which foul the shells of the farmed shellfish, or foul the ropes, nets or rafts associated with this activity are also likely to be removed during harvesting and maintenance activities.

19. Removal of target species

The removal of target (aquaculture) species can occur where natural spatfall is required to stock the ropes and lines. Mussels settling on artificial infrastructure, as opposed to natural mussel beds could lead to a decrease in wild settlement and impact natural populations. However, there is no evidence of this occurring in the literature, in areas of good natural spatfall, the impact should be limited due to the high numbers of spat in the water column.

20. Smothering and siltation rate changes ('Light' deposition)

Construction and harvesting operations related to subtidal raft culture may redistribute and suspend sediment into the water column, leading to potential smothering of benthic habitats and species. In addition, the placement of shellfish rafts or anchoring and mooring infrastructure on the seabed may smother species directly underneath, leading to localised displacement. The accumulation of biodeposits and shell fragments on the seabed is one of the most notable pressures that occurs due to shellfish aquaculture (Huntington et al., 2006; Cao et al., 2007; Bouchet and Sauriau 2008; McKindsey et al., 2011; Grant et al., 2012; Forde et al., 2015; ICES, 2020). Callier et al. (2007) concluded that suspended mussel culture can increase sedimentation by a factor of 1.3–5.5.

Biodeposition on the seabed can lead to smothering of sensitive flora and a potential change in benthic community structure. For example, seagrass has been shown to decrease in abundance near oyster culture areas compared to undisturbed areas and can become absent after prolonged exposure to increased sedimentation (Everett et al., 1995). Ysebaert et al. (2009) found that the impact of biodeposition from mussel culture can impact benthic communities, with the species composition shifting to opportunistic species that are typically present in organically enriched fine sediments. The degrading of *Sabellaria* reefs in the Bay of Mont-Saint-Michel, France has been attributed to smothering from mussel faeces (Desroy et al., 2011) and the accumulation of faeces and pseudofaeces can also result in locally anoxic sediments (Kaiser et al., 1998). Maerl beds underneath or adjacent to mussel farms have been shown to experience significant declines in live maerl and declines in the diversity of associated fauna due to an increase in fine sediments reaching the seafloor and filling the gaps/microhabitat between the maerl (Barbera et al., 2003; Peña and Bárbara, 2008).

21. Synthetic compound contamination

Synthetic compounds are used within the aquaculture industry such as antifoulants, pesticides, pharmaceuticals and parasiticides. In general, when compared to other aquaculture activities (for example subtidal fish cages), where contaminants can occur as a result of synthetic feeds, shellfish aquaculture does not generally require the input of chemicals (Forrest et al., 2009, Bannister et al., 2019). The amount of chemicals used in shellfish aquaculture has been described as negligible in Europe and the UK (OSPAR Commission, 2009).

22. Transition elements & organo-metal (e.g. TBT) contamination

No direct evidence was found regarding the use of transition elements and organo-metals in subtidal shellfish aquaculture. Metals, such as copper, have been used in aquaculture as antifoulants (Bannister et al. 2019).

23. Underwater noise changes

Underwater noise can occur from the installation of aquaculture infrastructure or the use of vessels during cultivation and harvesting operations. The impacts of noise from vessels used for cultivation could be lower in magnitude than typical vessel traffic, but this will be area-specific and could still potentially affect species sensitive to noise (Clement et al., 2013).

24. Visual disturbance

Visual disturbance can occur by vessel movement directly related to the construction and cultivation practices associated with subtidal shellfish aquaculture using rafts. The construction of aquaculture infrastructure is characterised by a short period of temporary disturbance, followed by the operational phase where disturbances are caused sporadically during maintenance, harvesting and reseeding activities (Becker et al., 2011).

There are concerns that birds in the vicinity of aquaculture sites could be disturbed/displaced by the presence of personnel or vessels and artificial lights (ICES, 2022).

25. Water flow changes

The presence of suspended shellfish in the water column can impact the tidal currents in the local area, by increasing surface friction and absorbing wave energy (Lin et al., 2016). There is the potential for water flow changes to occur both within and outside shellfish farms as flow is diverted around the farm. The effects of water flow changes, particularly at large aquaculture sites, can lead to changes in wave formation and distort water stratification which can have an effect on nutrient supply, dispersal of material and suspended sediment concentrations (Mascorda Cabre et al., 2021).

26. Wave exposure changes

There is the potential that the presence of shellfish and rafts in the water column could change wave exposure of a site, dampening wave action (ICES, 2020). Changes in wave exposure could affect physical processes such as sediment transport and also lead to changes in habitats and species communities.

Subtidal Shellfish Aquaculture using Rafts

Step 6: Next Steps

This Aquaculture Activity Assessment, along with the AWAA Mapping Tool, Dashboard, and Evidence Database, provide a useful starting point for users to further investigate the potential impacts from growing subtidal shellfish using rafts on the marine environment. Steps 1 to 5 of this Assessment have been designed to provide guidance on how the Project resources can be used to inform an environmental appraisal process.

Steps 1 to 5 provide the user with an initial understanding of the potential pressures occurring from an aquaculture activity and the tools to identify the most sensitive biotopes and species in an area of interest to the potential impacts from the proposed activity. Step 4 of this assessment should be repeated for all pressures identified in Step 2 to gain a full understanding of the sensitivity of biotopes and species to the activity.

However, to fully understand the impact of a specific aquaculture activity, the user needs to consider the footprint, location, intensity of the activity and the methods behind construction, operation and harvesting. Specific details about a proposed activity have the potential to change which pressures may occur, along with the exposure and significance of the effect of that pressure on relevant biotopes and species.

Environmental appraisals should also consider indirect impacts on biotopes and species from the proposed activities, for example, the impact on a habitat that provides food for a protected species. Whilst indirect impacts have not been included in the AWAA resources, it is important to consider how they could potentially have an impact. The environmental appraisal process may also consider the potential interactions between pressures which could exacerbate any potential impacts from pressures on their own.

Finally, it may be necessary to consult locally and to undertake area-specific surveys to gain further insight into potentially sensitive biotopes and species in the vicinity of a proposed activity.

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Abbreviations

AWAA	Aquaculture Activity Assessment
ICES	International Council for the Exploration of the Sea
INIS	Invasive Non-Native Species
MarESA	Marine Evidence based Sensitivity Assessment
MPA	Marine Protected Area
NRW	Natural Resources Wales
OSPAR	Cooperative of 15 governments and the EU for the Protection of the Marine environment of the North East Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
PSU	Practical Salinity Units
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
TBT	Tributyltin
UK	United Kingdom
US	United States

Data Archive Appendix

Data outputs associated with this project are archived in [NRW to enter relevant corporate store and / or reference numbers] on server–based storage at Natural Resources Wales.

Or

No data outputs were produced as part of this project.

The data archive contains: [Delete and / or add to A-E as appropriate. A full list of data layers can be documented if required]

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] A full set of maps produced in JPEG format.

[C] A series of GIS layers on which the maps in the report are based with a series of word documents detailing the data processing and structure of the GIS layers

[D] A set of raster files in ESRI and ASCII grid formats.

[E] A database named [name] in Microsoft Access 2000 format with metadata described in a Microsoft Word document [name.doc].

[F] A full set of images produced in [jpg/tiff] format.

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