AWAA Aquaculture Activity Assessment:

Intertidal Ground Laid Shellfish Aquaculture

Report No: 719

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Mae'r asesiad hwn yn berthnasol i'r rhai sy'n asesu effeithiau posibl dyframaethu pysgod cregyn wedi'u gosod ar dir rhynglanwol. 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 intertidal ground laid shellfish aquaculture. 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.

Intertidal Ground Laid Shellfish Aquaculture

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.

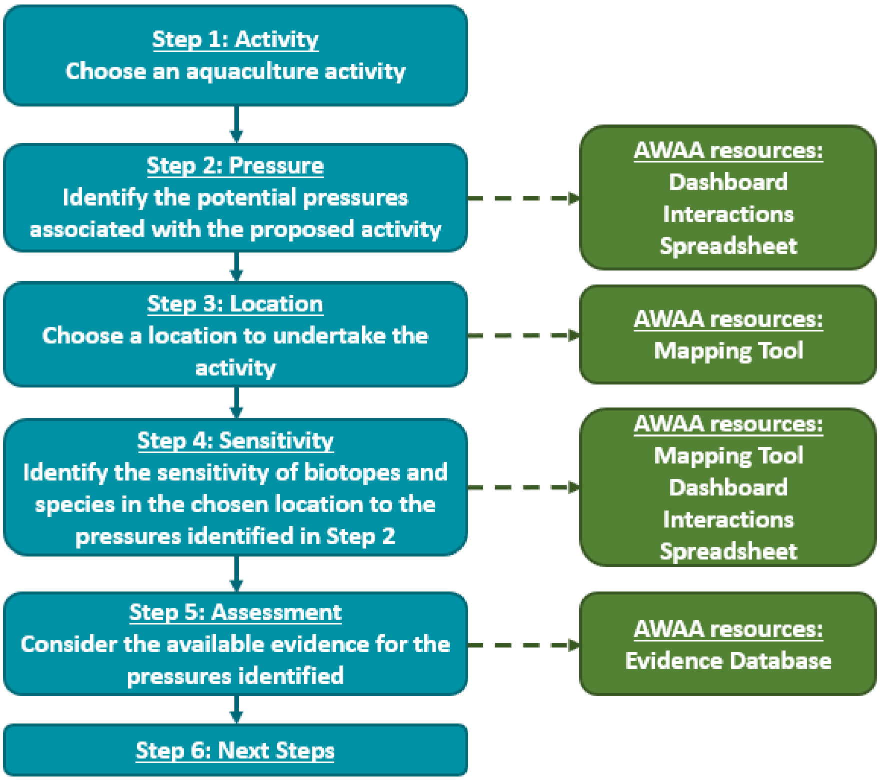

Figure 1. Flow diagram showing the step-by-step process of using the Project resources.

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, Interactions Spreadsheets and the Mapping Tool.

Intertidal Ground Laid Shellfish Aquaculture

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 the intertidal aquaculture activity of cultivating shellfish using ground laid methods.

Species cultivated

In the UK, mussels, oysters and clams are the usual species grown in intertidal ground laid shellfish aquaculture activities.

Mussel species include the blue mussel (*Mytilus edulis*) (Figure 2).

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

Clam species include the native clam (*Ruditapes decussatus*), the non-native Manila clam (*Ruditapes philippinarum*), and the non-native American hard shell clam (*Mercenaria mercenaria*).

Infrastructure and equipment

Relatively limited infrastructure is required for intertidal ground laid shellfish compared to other aquaculture activities. Equipment for collecting, laying and harvesting the shellfish could include the use of vessels with dredges at high tide, or vehicles to access the foreshore at low tide.

Clams require soft substrate to grow as they burrow into the sediment. They can be grown in plots under netting to deter predators or semi buried in bags in the substrate. The netting and bags are buried to around 10cm with ropes and metal hooks used to anchor them into the substrate (Seafish, 2005a).

Figure 2. Ground laid mussels (Photo: W. J. Jones – Deepdock).

General methods for growing and harvesting

Mussel seed stock can be collected by dredging from vessels at high tide or hand gathered from natural beds at low tide in the summer to early autumn. One year old mussels with shell sizes between 15-40mm are collected, with the ideal range between 25-35mm. The mussel seed is normally relayed at a lower density to encourage growth and the shells to harden. However, stocking density varies across producers and sites ranging from 10-100 tonnes per hectare (Seafish, 2005b; O'Biern et al., 2022). Mussel seed can be laid in the intertidal zone from a vessel at high tide, or by hand or from a vehicle at low tide.

Once laid, it can take one to three years for the mussel to reach marketable size. At which point, they can be harvested either by hand or mechanically from a vessel. Hand gathering involves raking and picking the mussels when the tide is out, whereas mechanical harvesting usually requires the use of mussel dredges from purpose-built shallow draft vessels when the tide is in. The mussel dredges can be up to 2m in width, consisting of a mesh bag with a blade, which is towed along the top of the seabed to remove the mussel (Eastern Inshore Fisheries and Conservation Authority (IFCA), 2023). The dredges are typically deployed using beams and mechanised winches from the side or back of the vessel.

Ground laid Pacific oyster aquaculture activities typically require hatchery-produced seed. A range of sizes can be laid, between 1–2g live weight, which generally require fences or net covers for protection from predators, or up to 10g live weight. The oysters are laid in the intertidal on either a firm substrate, or a soft substrate which has had a pre-application of shell, gravel or cultch. The oysters are generally laid at densities of approximately 200–400 per m^2 to ensure limited husbandry is required until the oysters reach marketable size (Towers, 2010). Once laid, depending on the location, it can take between nine months to four years to reach marketable size (O'Biern et al., 2022).

Once at marketable sizes of approximately 70–100g live weight, the oysters can be hand or mechanically harvested. Hand gathering of oysters occurs when the tide is out, and mechanical harvesting occurs via dredging from a vessel when the beds are submerged. Oyster or ladder dredges are often used, consisting of a metal frame with parallel bars at the base, attached to a mesh (usually metal) bag with 'skis' which allow the dredge to move across the surface of the seabed when towed. The dredges are typically deployed using beams and mechanised winches from the side or back of a vessel.

Clams are cultivated at some locations in the south of the UK. Seed clams are obtained from commercial hatcheries between 4–30mm in length (Seafish, 2005a). The clams are laid at densities of between 400–800 per m^2, typically underneath nets, and once laid they can take up to three years to grow to marketable size. Toothed or box dredges deployed from vessels can be used when the tide is in to harvest the clams. The dredge consists of a metal frame, with a mesh bag and a row of teeth at the opening of the dredge. The dredges are towed through the sediment to remove the clams which are retained in the dredge.

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

Intertidal Ground Laid Shellfish Aquaculture

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 intertidal ground laid shellfish 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, vessels or vehicles 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	Dredging mussel seed, trampling and vehicle movement and mechanical or hand harvesting methods could cause abrasion
Barrier to species movement	The physical obstruction of species movements and including local movements	Intertidal cultivation plots may present a barrier to species movement or feeding birds

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 feeders 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. Dredging seed 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 during the collection of seed 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, machinery or infrastructure used during the cultivation or collection of seed 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 vehicle or machinery oil or fuel leaks and spills

Pressure name	Description	Pathway from aquaculture activity
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 INIS stock could spread to surrounding areas
Litter	Any manufactured or processed solid material from anthropogenic activities discarded, disposed or abandoned	Netting, rope, 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 & microbiota; faecal matter from marine animals; or flocculated colloidal organic matter	Introduction of organic matter through farmed species' bio-deposits
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 dredging or from placement of netting or bags on the seabed

Pressure name	Description	Pathway from aquaculture activity
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 all harvesting and extraction activities	Ingestion of planktonic communities by filter feeders, or the removal of pests or biofouling species
Removal of target species	The commercial exploitation of fish & shellfish stocks	Collection of seed stock from wild beds or 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)	The effects of dredging causing the resuspension of sediments and/or the 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 pesticides
Underwater noise changes	Increases over and above background noise levels at a particular location	Noise generated by vessels and/or machinery during collection, operation and harvesting

Pressure name	Description	Pathway from aquaculture activity
Vibration (Pressure from Natural England, 2022)	Vibration from direct sources (e.g. drilling, trawling, dredging etc.)	Vibration generated by vessels and/or machinery during collection, 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, vehicle or personnel movement
Water flow (tidal current) changes, including sediment transport considerations	Changes in water movement associated with tidal streams, prevailing winds and ocean currents	Intertidal cultivation plots could reduce flow speeds, increase turbulence or alter water flow direction

Intertidal Ground Laid Shellfish Aquaculture

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 not 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;
- Rights of way, and
- Other users of the area.

To avoid exposure to strong tides, current and weather, sheltered coastal inlets and estuaries tend to be suitable locations for intertidal ground laid shellfish aquaculture. Shellfish are typically grown in the low intertidal zone to ensure they are covered by seawater for the majority of the time to promote feeding and growth. Areas of high turbidity are usually avoided for ground laid mussel and oyster cultivation to reduce the potential for smothering. However, regular tidal flow is required to ensure a good supply of food. Good water quality is also essential, to enable a shellfish production area classification of A or B, which determines the treatment required before live bivalve molluscs may be marketed for human consumption. While oysters and mussels are tolerant of low seawater salinities e.g. 20 practical salinity units (PSU), optimum growth occurs at salinities greater than 25 PSU. However, areas of lower salinity can be advantageous to reduce predation from marine invertebrates such as starfish and crabs (Karayücel, 1996). Disease and the presence of INIS may also influence the selection of areas.

Mussels and oysters can be grown on rock, shingle, shell material and mud or sand substrates. Clams require sand, gravel or mud substrates in order to burrow into the sediment.

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 in the Dyfi Estuary is provided in Step 4 that demonstrates how the AWAA Mapping Tool and Dashboard can be used if you are considering growing intertidal ground laid shellfish.

Intertidal Ground Laid Shellfish Aquaculture

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 case study focussing on the Dyfi Estuary is presented below to demonstrate how the AWAA Mapping Tool and Dashboard can be used to identify the 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 intertidal ground laid shellfish aquaculture identified in Step 2, Table 1:

1. Removal of non-target species; and

2. Visual disturbance.

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. Removal of non-target species

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

- Zoom in on the Dyfi Estuary;
- Select the aquaculture activity ‘Intertidal Ground Laid Shellfish’; and
- Select the desired pressure ‘removal of non-target species’.

The user will then be able to see the individual biotopes displayed in different colours based on their sensitivity to the pressure selected.

For example, Figure 3 shows the sensitivity of biotopes in the Dyfi Estuary to the pressure removal of non-target species. 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 ‘Intertidal Ground Laid Shellfish’;
- Select the pressure ‘removal of non-target species’; 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 Dyfi Estuary example, the biotopes from the AWAA Dashboard considered most sensitive to the removal of non-target species from intertidal ground laid shellfish aquaculture are shown in **Figure 3**. The biotopes *Ascophyllum nodosum* on full salinity mid eulittoral mixed substrata (LR.LLR.F.Asc.X), *Ascophyllum nodosum* on full salinity mid eulittoral rock (LR.LLR.F.Asc.FS), and *Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock (LR.LLR.FVS.AscVS) have been assessed as having a high sensitivity to the pressure removal of non-target species in MarESA (Tyler-Walters et al., 2022). There are nine biotopes which have a medium level of sensitivity to the pressure, including biotopes on rock and mixed substrata containing the seaweeds *Fucus vesiculosus*, *Fucus spiralis* and *Pelvetia canaliculata* as well as the biotope *Macoma balthica and Arenicola marina* in littoral muddy sand (LS.LSa.MuSa.MacAre). There are ten biotopes which have a low sensitivity to the removal of non-target species. Please see the AWAA Final Report to understand the process of how confidence was assigned by MarESA to the sensitivity scores. The pressure was also not considered relevant by MarESA to three biotopes in the proposed activity area and the pressure was not assessed for one biotope. 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, large shallow inlets and bays, mudflats and sandflats not covered by seawater at low tide and/or reef within the Lleyn Peninsula and the Sarnau Special Area of Conservation (SAC) and Dyfi Site of Special Scientific Interest (SSSI) with some of the biotopes also listed as Section 7 habitats.

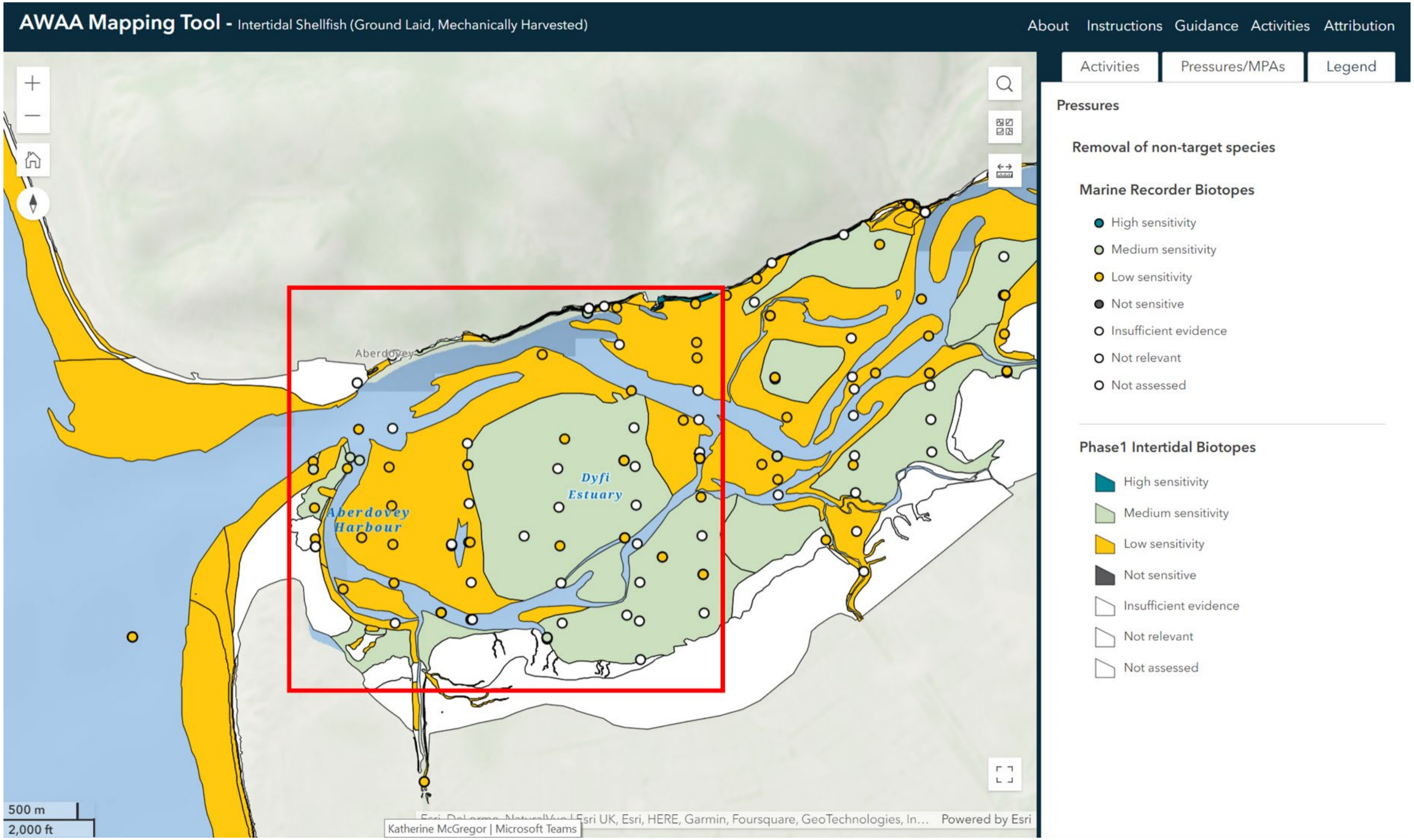

Figure 3. Use of the AWAA Mapping Tool to identify the proposed aquaculture activity location in the Dyfi Estuary and the biotopes overlapping with the proposed area (red box).

Table 2. The sensitivity of biotopes to the pressure ‘removal of non-target species’ using the example location of Dyfi Estuary and the aquaculture activity of growing intertidal ground laid shellfish. 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
Ascophyllum nodosum and *Fucus vesiculosus* on variable salinity mid eulittoral rock	LR.LLR.FVS.AscVS	High [High conf.]	Estuarine rocky habitats	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Large Shallow Inlets and Bays; Reef; Moderately exposed sand
Ascophyllum nodosum on full salinity mid eulittoral mixed substrata	LR.LLR.F.Asc.X	High [High conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide; Reef
Ascophyllum nodosum on full salinity mid eulittoral rock	LR.LLR.F.Asc.FS	High [High conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Cerastoderma edule and polychaetes in littoral muddy sand	LS.LSa.MuSa.CerPo	Medium [High conf.]	Intertidal mudflats	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Fucus ceranoides on reduced salinity eulittoral rock	LR.LLR.FVS.Fcer	Medium [Medium conf.]	Estuarine rocky habitats	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Mudflats and sandflats not covered by seawater at low tide; Reef; Moderately exposed sand
Fucus spiralis on full salinity sheltered upper eulittoral rock	LR.LLR.F.Fspi.FS	Medium [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Large Shallow Inlets and Bays; Reef
Fucus spiralis on sheltered upper eulittoral rock	LR.LLR.F.Fspi	Medium [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Fucus vesiculosus on mid eulittoral mixed substrata	LR.LLR.F.Fves.X	Medium [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide; Reef; Moderately exposed sand

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
Fucus vesiculosus on variable salinity mid eulittoral boulders and stable mixed substrata	LR.LLR.FVS.FvesVS	Medium [Medium conf.]	Estuarine rocky habitats	Lleyn Peninsula and the Sarnau SAC	Estuaries; Reef
Pelvetia canaliculata and barnacles on moderately exposed littoral fringe rock	LR.MLR.BF.PelB	Medium [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Reef
Pelvetia canaliculata on sheltered littoral fringe rock	LR.LLR.F.Pel	Medium [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Large Shallow Inlets and Bays; Reef; Moderately exposed sand
Pelvetia canaliculata on sheltered variable salinity littoral fringe rock	LR.LLR.FVS.PelVS	Medium [Medium conf.]	Estuarine rocky habitats	Lleyn Peninsula and the Sarnau SAC	Estuaries; Reef
Macoma balthica and *Arenicola marina* in littoral muddy sand	LS.LSa.MuSa.MacAre	Medium [Low conf.]	Intertidal mudflats	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Semibalanus balanoides and *Littorina* spp. on exposed to moderately exposed eulittoral boulders and cobbles	LR.HLR.MusB.Sem.LitX	Medium [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide; Reef
Lanice conchilega in littoral sand	LS.LSa.MuSa.Lan	Low [High conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Nephtys cirrosa dominated littoral fine sand	LS.LSa.FiSa.Po.Ncir	Low [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide

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
Polychaetes and *Angulus tenuis* in littoral fine sand	LS.LSa.FiSa.Po.Aten	Low [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Polychaetes in littoral fine sand	LS.LSa.FiSa.Po	Low [Medium conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Amphipods and *Scolelepis* spp. in littoral medium-fine sand	LS.LSa.MoSa.AmSco	Low [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Bathyporeia pilosa and *Corophium arenarium* in littoral muddy sand	LS.LSa.MuSa.BatCare	Low [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Eurydice pulchra in littoral mobile sand	LS.LSa.MoSa.AmSco.Eur	Low [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Hediste diversicolor and *Macoma balthica* in littoral sandy mud	LS.LMu.MEst.HedMac	Low [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Hediste diversicolor in littoral mud	LS.LMu.UEst.Hed	Low [Low conf.]	Intertidal mudflats	Lleyn Peninsula and the Sarnau SAC	Estuaries
Hediste diversicolor, *Macoma balthica* and *Scrobicularia plana* in littoral sandy mud shores	LS.LMu.MEst.HedMacScr	Low [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Talitrids on the upper shore and strand-line	LS.LSa.St.Tal	Low [Low conf.]	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide

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
Barren littoral coarse sand	LS.LSa.MoSa.BarSa	Not relevant	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Barren littoral shingle	LS.LCS.Sh.BarSh	Not relevant	Not Section 7	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Large Shallow Inlets and Bays; Moderately exposed sand
Barren or amphipod-dominated mobile sand shores	LS.LSa.MoSa	Not relevant	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries
Verrucaria maura on very exposed to very sheltered upper littoral fringe rock	LR.FLR.Lic.Ver.Ver	Not relevant	Not Section 7	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Large Shallow Inlets and Bays; Reef; Moderately exposed sand
Yellow and grey lichens on supralittoral rock	LR.FLR.Lic.YG	Not relevant	Not Section 7	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI	Estuaries; Large Shallow Inlets and Bays; Reef; Moderately exposed sand
Polychaete/amphipod-dominated fine sand shores	LS.LSa.FiSa	Not assessed	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries; Large Shallow Inlets and Bays; Mudflats and sandflats not covered by seawater at low tide
Polychaete/bivalve-dominated mid estuarine mud shores	LS.LMu.MEst	Not assessed	Intertidal mudflats	Lleyn Peninsula and the Sarnau SAC	Estuaries
Polychaete/bivalve-dominated muddy sand shores	LS.LSa.MuSa	Not assessed	Intertidal mudflats	Lleyn Peninsula and the Sarnau SAC	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Salicornia dominated saltmarsh	LS.LMp.Sm.SM8	Not assessed	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries
Saltmarsh	LS.LMp.Sm	Not assessed	Not Section 7	Lleyn Peninsula and the Sarnau SAC	Estuaries

2. Visual disturbance

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 'Intertidal Ground Laid Shellfish';
- Select the pressure 'visual disturbance'; 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 Dyfi Estuary 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:

- Lleyn Peninsula and the Sarnau SAC;
- Dyfi Estuary Special Protection Area (SPA);
- Northern Cardigan Bay SPA; and
- Dyfi SSSI.

Redshank, a feature of the Dyfi SSSI, and red-throated diver, a feature of Northern Cardigan Bay SPA, have been assessed as having a high sensitivity to the pressure of visual disturbance in the Natural England (2022) sensitivity assessment. While White-Fronted Goose, a feature of the Dyfi Estuary SPA and Dyfi SSSI, and Wigeon a feature of the Dyfi SSSI, have been assessed as having a medium sensitivity to the pressure. Bottlenose Dolphin, Grey seal and Otter are features of the Leyn Peninsula and the Sarnau SAC. Grey Seal have been assessed as having a low sensitivity to visual disturbance while Bottlenose Dolphin and Otter are not considered to be sensitive to visual disturbance. Please see the AWAA Final Report to understand the process of how confidence was assigned by Natural England to the sensitivity scores. The AWAA Final Report provides further information on assessment conclusions such as any 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 the Dyfi Estuary, 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 'visual disturbance' using the example location of Dyfi Estuary and the aquaculture activity of growing intertidal ground laid shellfish. 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
Redshank (breeding)	*Tringa totanus*	High [High conf.]	No	Dyfi SSSI
Redshank (non-breeding)	*Tringa totanus*	High [High conf.]	No	Dyfi SSSI
Red-throated diver (breeding)	*Gavia stellata*	High [Medium conf.]	No	Northern Cardigan Bay SPA
Red-throated diver (non-breeding)	*Gavia stellata*	High [Medium conf.]	No	Northern Cardigan Bay SPA
White-fronted goose (non-breeding)	*Anser albifrons*	Medium [High conf.]	No	Dyfi Estuary SPA; Dyfi SSSI
Wigeon (non-breeding)	*Anas penelope*	Medium [High conf.]	No	Dyfi SSSI
Grey seal	*Halichoerus grypus*	Low [High conf.]	No	Lleyn Peninsula and the Sarnau SAC
Bottlenose dolphin	*Tursiops truncatus*	Not sensitive [High conf.]	Yes	Lleyn Peninsula and the Sarnau SAC
Otter	*Lutra lutra*	Not sensitive [High conf.]	Yes	Lleyn Peninsula and the Sarnau SAC; Dyfi SSSI

Intertidal Ground Laid Shellfish Aquaculture

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 intertidal ground laid shellfish aquaculture identified in Step 2 (Table 1) are provided below. The evidence summaries for the two pressures used in the Dyfi Estuary case study example in Step 4 are provided below in sections 17 and 23.

1. Above water noise

Although no evidence was found in the scientific literature for this pressure with respect to intertidal ground laid shellfish aquaculture, above water noise is expected to occur during collection, laying and harvesting of shellfish. Above water noise has the potential to disturb bird species, particularly wading birds in the intertidal zone, and seals which haul out on the shore in the vicinity of the activity.

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

Abrasion or disturbance of the seabed is likely to occur during the collection and harvesting of shellfish with hand rakes or mechanical dredges and the movements of vehicle or farm personnel walking between cultivation sites.

Harvesting by hand is likely to cause less of an impact to the seabed compared to harvesting with hand tools such as rakes. Whiteley and Bendell-Young (2007) found that the use of hand rakes for clam mariculture can mix sediment layers and alter infaunal communities over the short term, however, raking is unlikely to resuspend sediments during low tide. A study by Kaiser et al. (2001) showed that raking cockles led to community changes that took two months or more to recover. Manual harvesting methods have been shown to have less on an initial impact on seagrass compared to mechanical methods (Ferriss et al., 2019). If the collection and harvesting of intertidal ground laid shellfish are conducted by hand, the impacts from the activities should be less and localised compared to the impacts from using mechanical techniques.

The collection of seed stock and harvesting mussels using mechanical dredges is common practice in the UK. It involves towing a dredge across the surface of the seabed to remove the mussel, which can lead to both surface and sub-surface scarring of the seabed (Shellfish Industry Development Strategy, 2008) and increased sediment suspension in the water column. In relation to mussel seed collection, Kaiser et al. (1998) concluded that as seed mussel beds occur in discrete areas, the disturbance from dredging is generally localised with the seasonal nature of seed settlement allowing for up to one years' recovery prior to collection the following year. Saurel et al. (2004) also stated that the accumulation of mud in mussel seed beds detaches the bed from the substratum, meaning that dredging can often leave the underlying (pre-settlement) substratum relatively undisturbed with the main impacts of seed mussel exploitation likely to be indirect ecological effects. Abrasion could have a strong influence on benthic communities beneath and around farm sites or seed collection areas, for example, directly causing damage to species, changing turbidity or smothering (Forrest et al, 2009) and dredging may lead to decreases in the abundance and diversity on benthic assemblages (Toupoint et al., 2008).

Disturbance in the form of trampling has been shown to affect seagrass beds. It is important to note, however, that the impacts of trampling can vary depending on the type of substratum (Major et al., 2004).

Abrasion from intertidal shellfish culture can also occur from vehicle movements. A study undertaken in Ireland by Forde et al (2015) showed that disturbance from shore access to cultivation areas by vehicles can lead to compaction of the sediments. Pauls *et al*. (2017) investigated the impact of vehicle access on seagrass at Angle Bay, Wales, and the timescale for recovery after one impact event. The immediate disturbance of one tyre track led to an 80-90% decrease in seagrass blade frequency localised to the track. The seagrass took two years to fully recover after the tyre tracks caused compression of the sediment and local changes in hydrology.

Other studies (Everett et al., 1995, Beninger and Shumway, 2018) corroborate these impacts and state that the movement of shellfish farmers and their vehicles can negatively impact sediment dwelling organisms, such as mudflat infauna and native flora. For example, Everett et al. (1995) found that oyster culture in the United States resulted in a 25% decline in the abundance of seagrass (*Zostera marina*) compared to undisturbed areas over the course of a year, and that seagrass was absent under the oyster culture after 18 months. This decrease was attributed to both an increase in sedimentation under the culture and physical disturbance of the seabed from placement and harvesting processes.

3. Barrier to species movement

Intertidal ground laid aquaculture has the potential to act as a barrier to protected species that use the intertidal zone for foraging, such as seabirds and otters.

In general, studies have found that wading birds will avoid areas of intertidal shellfish aquaculture (Kaiser et al, 1998; Ahmed and Solomon, 2016; Burger 2018) with extensive intertidal cultivation plots potentially depriving birds of feeding habitats. In addition, associated shellfish husbandry practices could also disturb or act as a barrier to feeding or roosting birds (Kaiser et al., 1998). Some intertidal ground laid shellfish aquaculture practices deploy infrastructure to deter birds from particular areas. For example, a study by Godet et al. (2009) found that the spatial distribution of oystercatchers in Normandy, France, was significantly reduced around clam aquaculture sites due to the presence of anti-predator netting. Methods can be employed to deter bird predation on bottom-grown bivalve cultivation, and hence exclude them from cultivation areas. Examples include the presence of dogs, scarecrows and falcons, or the use of flashing lights or sound (Bord Iascaigh Mhara, 2008).

It is likely that other species using the intertidal zone may be impacted by the presence of ground laid shellfish aquaculture, for example, otters foraging on the shore, however, no direct mention of this was found in the scientific literature.

4. Changes in suspended solids (water clarity)

Collection or harvesting of shellfish using dredges has the potential to disturb the seabed leading to resuspension of sediments and increased turbidity in the water column (Mercaldo-Allen et al., 2011). 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. 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 collection of seed stock. However, no evidence was found in the scientific literature relating to the collision of species above water with the collection of seed stock. 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 operational vessels during the 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 intertidal ground laid shellfish aquaculture.

However, it is expected that this pressure in the form of fuel or oil leaks and spills could occur through the use of vessels, machinery or vehicles during seed collection, construction and harvesting processes. While there are no studies on the impacts of intertidal ground laid shellfish aquaculture causing hydrocarbon and PAH contamination, the user should consider the applicability of evidence from other activities that could generate similar pressures.

9. 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 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 also 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.

10. 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*. Evidence suggests, however, that Pacific oyster beds could increase settlement opportunities for mussels and other species which require hard substrates to colonise (Fey et al., 2010; Tillin et al., 2020). Oyster beds can increase habitat heterogeneity and therefore can 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.

11. Litter

In general, aquaculture activities are recognised as a potential pathway for the introduction of marine litter. The introduction of litter from intertidal ground laid shellfish aquaculture practices are likely to be less than other aquaculture activities as the activity does not normally include artificial infrastructure. 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.

12. Nutrient enrichment

Shellfish have the potential to provide an ecosystem service by acting as a bioremediator and limiting nutrient enrichment (International Council for the Exploration of the Sea (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).

13. 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. This 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. Trophic diversity can also be enhanced by the addition of shell fragments or whole shell valves which provide new habitat opportunities for invertebrates and other species groups (Callier et al. 2007).

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. Although there is limited information on effects on bivalve culture in the intertidal zone, most studies on organic enrichment of the seabed from shellfish farming have concluded that the effect is 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.

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

The use of dredges, for example, for harvesting or the collection of seed stock can lead to penetration and disturbance of the substrate below the surface of the seabed. It has been found that dredges for catching molluscs on the surface such as scallops, mussels and oysters, can create furrows of between 1–15cm in depth, however the depth will be dependent on the type of sediment, dredge and the presence/absence of dredge teeth (Eigaard et al., 2016). The impact of dredgers penetrating the seabed can lead to damage or mortality of benthic infauna, the resuspension of sediments and short to long-term change in the sediment surface.

No studies were found that investigated the impacts of seabed penetration from stationary aquaculture infrastructure, such as netting or bags used for intertidal clam bottom culture. However, penetration and/or disturbance of the substrate below the surface of the seabed could result from netting or bags used for intertidal clam bottom culture being placed or 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.

15. Physical change (to another seabed type)

Ground laid cultivation of bivalves on mudflats have the potential to create a hard-bottomed, three-dimensional structure on the top of the soft-bottomed seabed. As a result, species composition can change from soft bottom to hard bottom communities (ICES, 2020). The communities associated with bivalve culture have been shown to be highly diverse (Beadman et al., 2004) in comparison to communities living on soft-bottom habitats. The change in seabed type can lead to the competition for space between farmed shellfish and species which rely on a soft-bottom seabed, such as seagrass, maerl and benthic infauna, leading to a decline in these species (Wagner et al, 2012).

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. Oyster and mussels are 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).

16. Physical change (to another sediment type)

Large amounts of biodeposits or shell fragments from shellfish aquaculture have the potential to change sediments 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). 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 intertidal aquaculture which may also lead to the loss of fine particles and subsequently change infaunal community composition (ICES, 2020).

17. Removal of non-target species

Dredging as a means for harvesting or collecting seed stock may lead to the incidental capture of bycatch species or damage of species by the fishing gear. Bord Iascaigh Mhara (2008) stated that the main bycatch in seed mussel dredging in Ireland are invertebrate predators including starfish, crabs and common whelk. In addition, dredging can adversely affect benthic species via smothering from suspended sediments or exposing non-target species to predation (Shellfish Industry Development Strategy, 2008). Netting employed to reduce bird predation has also been associated with the entanglement of birds (ICES, 2022).

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 colonise the shells of the farmed shellfish or the infrastructure associated with this activity are also likely to be removed during harvesting and maintenance activities.

Entanglement is not expected to be an issue for this particular activity unless where netting, bags or ropes are used in clam culture.

18. Removal of target species

The removal of target (aquaculture) species occurs where seed stock is collected from natural seed beds. Murray et al. (2007) states that this removal cannot be interpreted as a negative effect of mussel culture on biodiversity as the removal of seed mussel from an intertidal site may allow underlying fauna to prosper in the newly exposed surface sediments. While this impact might not appear to be negative, it has to be assessed in context of the original habitat and whether that original habitat e.g. mussel bed is protected or not.

The overexploitation of mussel seedbeds in some parts of Europe has caused declines in eider duck and a reduction in the breeding success of oystercatchers who use the mussels as a food source (Kaiser et al., 1998; Bord Iascaigh Mhara, 2008; European Commission, 2015).

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

Dredging may redistribute and suspend sediment into the water column, leading to potential smothering of benthic habitats and species. In addition, the placement of shellfish 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). Bord Iascaigh Mhara (2008) described the smothering of benthic habitats by ground laid aquaculture activities indirectly affecting predators by smothering their prey.

Biodeposition on the seabed can lead to smothering of sensitive flora and a potential change in benthic community structure. 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 adjacent to mussel farms have been shown to experience significant declines in live maerl and in the diversity of associated fauna due to an increase in fine sediments from the mussel farm filling the gaps/microhabitat between the maerl (Barbera et al., 2003; Peña and Bárbara, 2008). However, as maerl are a subtidal species, the impacts of intertidal bivalve culture on maerl will depend on local hydrodynamics and the footprint of the intertidal operation.

20. 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 typically 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).

21. Underwater noise changes

Underwater noise can occur from 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).

22. Vibration

There is no evidence in the literature on the impacts of vibration occurring from the mechanical collection or harvesting of shellfish. Whilst some vibration will occur from the use of equipment such as dredges on the seabed, it is likely to be highly localised in scale and temporary in nature.

23. Visual disturbance

Visual disturbance can occur by vessel/vehicle or personnel movement directly related to the collection, cultivation and harvesting practices associated with intertidal ground laid shellfish. Disturbance is caused sporadically during collection, maintenance and harvesting activities (Becker et al., 2011).

Of particular concern is disturbance at seal haul-out sites, with the rate of disturbance been shown to increase significantly with increased harvesting (Becker et al., 2009). There are also significant concerns in relation to feeding birds in the vicinity of the aquaculture site, although there is little direct research on this impact. Maslo et al. (2020) found that tended intertidal aquaculture activities reduced the probability of shorebird presence by 1–7% in the US whereas untended aquaculture activities led to no detectable impacts. However, foraging rates were mostly influenced by environmental conditions as opposed to disturbance.

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). Sometimes methods are used to deliberately deter bird predation on bottom-grown bivalve cultivation, and hence exclude them from cultivation areas. Examples include the presence of dogs, scarecrows and falcons, or the use of flashing lights or sound (Bord Iascaigh Mhara, 2008).

24. Water flow changes

Bivalves grown directly on the seabed can turn the benthic surface into a three-dimensional structure which can increase flow turbulence above the reef, and reduce current speeds (Cannon et al., 2022). This can have implications on sediment transport (for example enhanced sedimentation), oxygen exchange, increase larval retention and increase food delivery. However, there is relatively little evidence in the literature regarding the impacts of wave exposure changes with shellfish aquaculture in the intertidal zone.

Intertidal Ground Laid Shellfish Aquaculture

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 intertidal ground laid shellfish 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
IFCA	Inshore Fisheries and Conservation Authorities
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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