AWAA Aquaculture Activity Assessment:

Intertidal Shellfish Aquaculture using Trestles or Poles

Report No: 718

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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 rhynglanwol gan ddefnyddio trestlau a pholion. 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 shellfish aquaculture using trestles and poles. 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 Shellfish Aquaculture using Trestles or Poles

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.

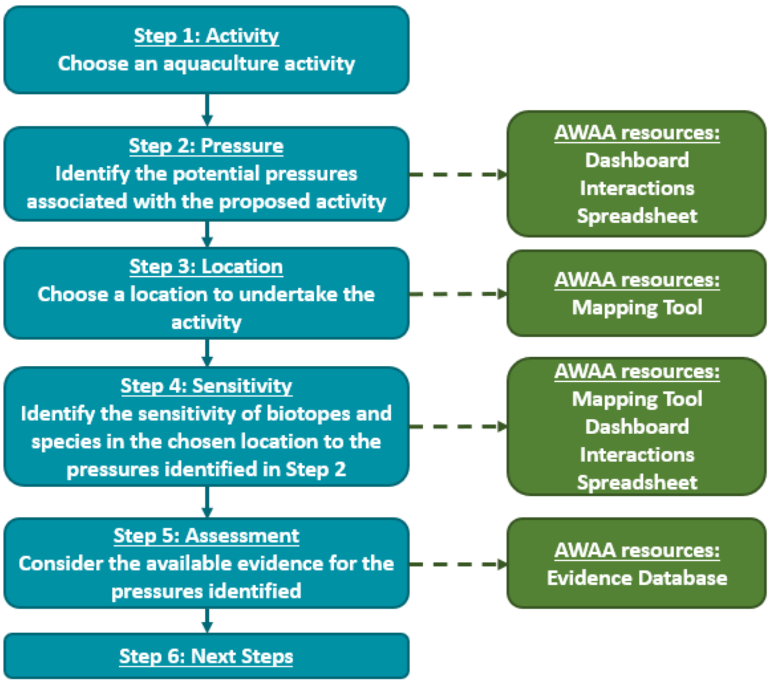

Figure 1. Flow diagram showing the step-by-step process of using the Project resources.

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 Shellfish Aquaculture using Trestles or Poles

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 on trestles or poles.

Species cultivated

In the United Kingdom (UK), oysters and mussels are the usual species grown on trestles or poles in intertidal shellfish aquaculture activities.

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

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

Infrastructure and equipment

Intertidal shellfish aquaculture using bags, baskets, lantern nets or lines requires the installation of infrastructure. Trestles or poles are driven into the seabed to support containers or lines of bivalve stock within the water column. This type of aquaculture activity is also known as ‘off-bottom’ aquaculture as the bivalve stock are not in direct contact with the seabed.

The principal infrastructure or equipment for off-bottom cultivation of oysters in the intertidal zone is usually trestles with accompanying bags, baskets or lantern nets. Typically, each steel trestle is between 0.6–1.0m in height, 2–3m in length and up to 1m in width. The trestles are arranged in lines perpendicular to the shore and support either mesh bags laid horizontally on top of the frames (Figure 2a), baskets[1] suspended from the top bars of the trestles (Figure 2b) or lantern nets strung between or from the trestles. Poles driven into the substrate with lines strung between can also be used to support baskets containing oysters.

Mussels can be cultivated in the intertidal zone on wooden poles driven vertically into the seabed, with lines for mussel attachment and growth either wound around individual poles

[1] such as ORTACS, Hexcyl (https://www.hexcylsystems.com.au/) or SEAPA (https://seapa.com.au/) baskets.

or strung between poles (Figure 2c). This method is known as ‘Bouchot’ mussels in France although it is not currently employed in the UK.

Intertidal aquaculture commonly employs tractors, quad bikes and trailers. Collection of wild mussel seed can involve vessels with mussel dredges.

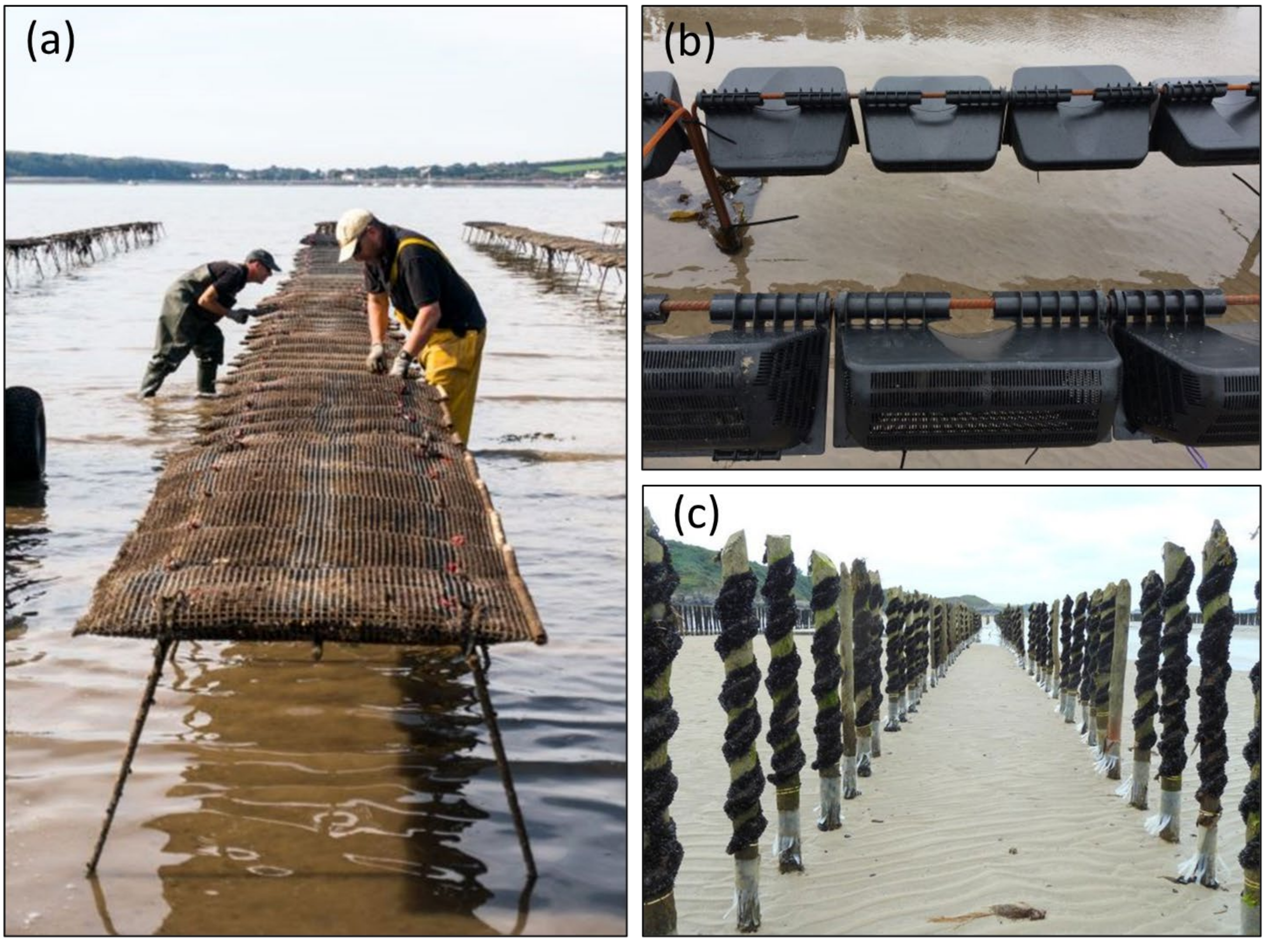

Figure 2. Off-bottom intertidal culture of shellfish; (a) Oysters lays using mesh bags on trestles (courtesy of Atlantic Edge Oysters) (b) Oyster lays using ORTAC baskets on trestles (courtesy of Atlantic Edge Oysters); (c) Mussels cultivated using Bouchot poles (source: http://www.christianlegac.com)

General methods for growing and harvesting

Intertidal aquaculture activities using trestles requires human intervention when the shellfish stock is exposed during part of the tidal cycle. For example, checking and maintaining the aquaculture infrastructure as well as stock husbandry which involves maintaining optimum stocking densities, size-grading of stock, as well as monitoring for health and disease. Farmed bivalves *in situ* do not require feeding via human intervention.

Depending on the bivalve species, stock for cultivation can be obtained either through wild spat settlement, collection of wild seed (i.e. juveniles), or from shellfish hatcheries. For oyster cultivation, seed oysters are normally sourced from dedicated oyster hatcheries. The oysters are available in a range of sizes (known as ‘grades’), from small seed oysters (approximately 6–7mm in diameter) up to larger semi-mature, part-grown (marketable size) oysters. Trestles can provide a variety of settlement surfaces for wild oyster spat development. Once settled, spat are often removed around 20–30mm in length and placed into bags. Where oysters are obtained from hatcheries, they are placed directly into the baskets or bags.

Stocking densities are dependent on size, with oysters graded or ‘thinned out’ every few weeks or months. As the oysters grow, stocking densities in the bags or baskets are progressively reduced with the mesh size gradually increased. The oysters are regularly inspected; and if grown in bags, turned on a regular basis. Grading, inspecting and turning oysters promotes water flow, enhances oyster growth and allows for health inspections, as well as predator and fouling organism removal.

For mussel cultivation, wild spat can be collected on ropes wound around Bouchot poles or lines suspended between poles which are then stripped and re-seeded when the mussels reach 10mm. Fibrous rope is often used to maximise the collection area for mussel spat. Wild seed is typically collected by hand or by dredging and is then seeded onto ropes. 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 Authorities (IFCA), 2023). The dredges are typically deployed using beams and mechanised winches from the side or back of the vessel.

After a period of time, depending on density of the mussel seed, thinning out may be required. Mussel seed is stripped off the line and put into long thin mesh socks with new fibrous ropes at a density of around 600 mussels per meter (Brixham Sea Farms, 2014). The line is reattached to the poles and the mussels reattach themselves to the new line by their byssal threads. Netting or mesh socking prevents the mussels falling off and reduces predation.

Although not common, mussel farmers in Wales have been known to grow mussels in bags on trestles in the intertidal area. Seed mussel is generally hand collected from nearby areas then grown within the bags. Like oyster cultivation, the bags are turned, the mussels thinned out and the mesh size of the bag increased as the mussels get larger.

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 Shellfish Aquaculture using Trestles or Poles

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 shellfish using trestles or poles 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	Potential 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, installation of infrastructure, trampling and vehicle movement 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	Potential 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	Trestles, 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	Intertidal cultivation plots could pose a collision threat to species moving close to shore particularly during high tides. The use of vessels with dredges during the 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 Hydrocarbons (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	Potential pathway from aquaculture activity
Introduction of light or shading	Direct inputs of light from anthropogenic activities. Also shading from structures etc.	Off-bottom intertidal cultivation plots may cause shading of benthic communities
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 the 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	Bags, 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 and microbiota; faecal matter from marine animals; or flocculated colloidal organic matter	Introduction of organic matter through farmed species' bio-deposits

Pressure name	Description	Potential 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 could occur from seed dredging or from trestles and poles
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
Removal of target species	The commercial exploitation of fish and 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 under and near the infrastructure

Pressure name	Description	Potential pathway from aquaculture activity
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 the addition of pesticides
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 dredging activities
Vibration (Pressure from Natural England, 2022)	Vibration from direct sources (e.g. drilling, trawling, dredging etc)	Vibration generated by vessels and/or machinery during dredging activities
Visual disturbance	The disturbance of biota by anthropogenic activities, (e.g. increased vessel movements)	Visual disturbance to 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
Wave exposure changes	Local changes in wavelength, height and frequency	Infrastructure could reduce wave action and impact local coastal processes, however this may not be an issue in sheltered locations

Intertidal Shellfish Aquaculture using Trestles or Poles

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 shellfish aquaculture using trestles or poles. Ideal locations include areas in the lower intertidal zone with low to moderate exposure (around 4 hours each side of the low tide), that are suitable for deployment of the infrastructure and easily accessible from the shore. If planning to use self-seeding techniques to gather shellfish spat in a chosen location, then consider the sources and natural availability of spat in the local area. A firm and stable sediment substrate, not rock or soft mud, at the chosen site is needed to install the trestles or poles. 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.

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 Taf estuary is provided in Step 4 that demonstrates how the AWAA Mapping Tool and Dashboard can be used if you are considering growing intertidal shellfish using trestles or poles.

Intertidal Shellfish Aquaculture using Trestles or Poles

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 the Taf Estuary is presented below to demonstrate the 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 intertidal shellfish aquaculture using trestles or poles identified in Step 2, Table 1:

1. Penetration and/or disturbance of the substrate below the surface of the seabed; and

2. Barrier to species movement.

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. Penetration and/or disturbance of the substrate below the surface of the seabed

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

- Zoom in on the Taf Estuary;
- Select the aquaculture activity ‘Intertidal Shellfish using Trestles or Poles’; and
- Select the desired pressure ‘penetration and/or disturbance of the substrate below the surface of the seabed’.

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 Taf Estuary to the pressure penetration and/or disturbance of the substrate below 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 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 Shellfish using Trestles or Poles';
- Select the pressure 'penetration and/or disturbance of the substrate below 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 Taf Estuary example, the sensitivity of biotopes to penetration and/or disturbance of the substrate below the surface of the seabed from intertidal shellfish aquaculture using trestles and poles are shown in **Table 2**. The biotope *Macoma balthica* and *Arenicola marina* in littoral muddy sand (LS.LSa.MuSa.MacAre) has been assessed as highly sensitive to the pressure penetration of the substrate in MarESA (Tyler-Walters et al., 2022). Four biotopes, including *Cerastoderma edule* and polychaetes in littoral muddy sand (LS.Lsa.MuSa.CerPo), *Fucus vesiculosus* on variable salinity mid eulittoral boulders and stable mixed substrata (LR.LLR.FVS.FvesVS), *Fucus vesiculosus* on mid eulittoral mixed substrata (LR.LLR.F.Fves.X) and *Mytilus edulis* beds on littoral mixed substrata (LS.LBR.LMus.Myt.Mx) have been assessed as having a medium sensitivity to the pressure. Eight of the biotopes in the example activity location are considered to have a low sensitivity to penetration of the substrate and one biotope was considered not sensitive. 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 one biotope in the proposed activity area and the pressure was not assessed for two biotopes. 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'.

All the biotopes identified form a component of a number of MPA features such as estuaries, large shallow inlets and bays, and/or mudflats and sandflats not covered by seawater at low tide within the Carmarthen Bay and Estuaries Special Area of Conservation (SAC) with some of the biotopes also listed as Section 7 habitats.

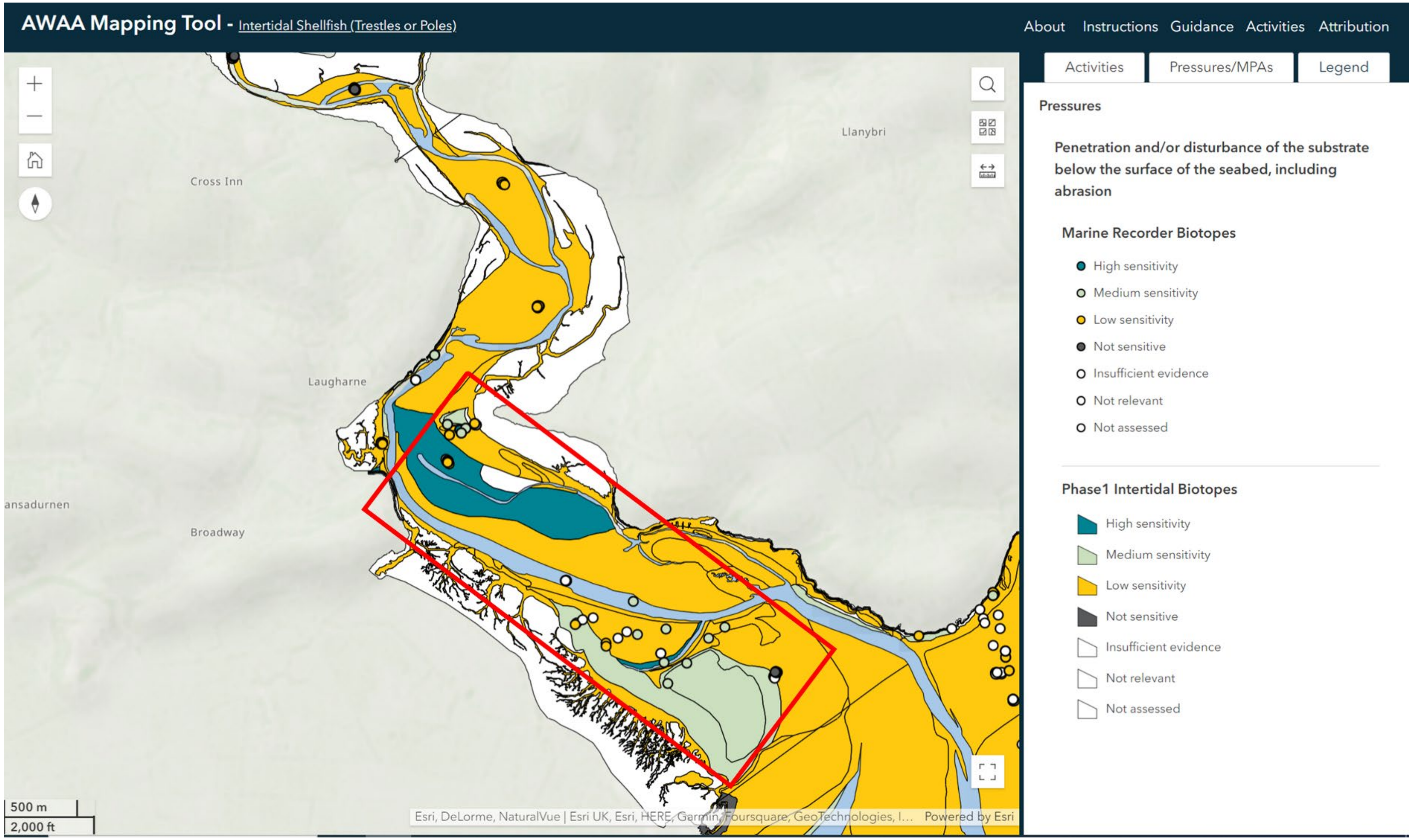

Figure 3. Use of the AWAA Mapping Tool to identify the proposed aquaculture activity location in the Taf Estuary and the biotopes overlapping with the proposed area (red box).

Table 2. The sensitivity of biotopes to the pressure ‘penetration and/or disturbance of the substrate below the surface of the seabed’ using the example location of the Taf Estuary and the aquaculture activity of growing intertidal shellfish using trestles or poles. 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
Macoma balthica and *Arenicola marina* in littoral muddy sand	LS.LSa.MuSa.MacAre	High [High conf.]	Intertidal mudflats	Carmarthen Bay and Estuaries	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Cerastoderma edule and polychaetes in littoral muddy sand	LS.LSa.MuSa.CerPo	Medium [High conf.]	Intertidal mudflats	Carmarthen Bay and Estuaries	Estuaries; Large shallow inlets and bays; Mudflats and sandflats not covered by seawater at low tide
Fucus vesiculosus on variable salinity mid eulittoral boulders and stable mixed substrata	LR.LLR.FVS.FvesVS	Medium [High conf.]	Estuarine rocky habitat	Carmarthen Bay and Estuaries	Estuaries
Fucus ceranoides on reduced salinity eulittoral rock	LR.LLR.FVS.Fcer	Medium [Medium conf.]	Estuarine rocky habitats	Carmarthen Bay and Estuaries	Estuaries; Large shallow inlets and bays; Mudflats and sandflats not covered by seawater at low tide
Mytilus edulis beds on littoral mixed substrata	LS.LBR.LMus.Myt.Mx	Medium [Medium conf.]	Not Section 7	Carmarthen Bay and Estuaries	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 [High conf.]	Not Section 7	Carmarthen Bay and Estuaries	Estuaries
Bathyporeia pilosa and *Corophium arenarium* in littoral muddy sand	LS.LSa.MuSa.BatCare	Low [Medium conf.]	Not Section 7	Carmarthen Bay and Estuaries	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Hediste diversicolor and *Macoma balthica* in littoral sandy mud	LS.LMu.MEst.HedMac	Low [High conf.]	Not Section 7	Carmarthen Bay and Estuaries	Estuaries; 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
Hediste diversicolor, *Macoma balthica* and *Scrobicularia plana* in littoral sandy mud shores	LS.LMu.MEst.HedMacScr	Low [High conf.]	Not Section 7	Carmarthen Bay and Estuaries	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Hediste diversicolor, *Macoma balthica* and *Eteone longa* in littoral muddy sand	LS.LSa.MuSa.HedMacEte	Low [High conf.]	Intertidal mudflats	Carmarthen Bay and Estuaries	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Eurydice pulchra in littoral mobile sand	LS.LSa.MoSa.AmSco.Eur	Low [High conf.]	Not Section 7	Carmarthen Bay and Estuaries	Estuaries; Large shallow inlets and bays; Mudflats and sandflats not covered by seawater at low tide
Polychaetes and *Angulus tenuis* in littoral fine sand	LS.LSa.FiSa.Po.Aten	Low [High conf.]	Not Section 7	Carmarthen Bay and Estuaries	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 [High conf.]	Not Section 7	Carmarthen Bay and Estuaries	Estuaries; Large shallow inlets and bays; Mudflats and sandflats not covered by seawater at low tide
Barren or amphipod-dominated mobile sand shores	LS.LSa.MoSa	Not Sensitive [Medium conf.]	Not Section 8	Carmarthen Bay and Estuaries	Estuaries; Large shallow inlets and bays
Fucus spiralis on sheltered variable salinity upper eulittoral rock	LR.LLR.FVS.FspiVS	Not Relevant	Estuarine rocky habitat	Carmarthen Bay and Estuaries	Estuaries
Polychaete/bivalve-dominated muddy sand shores	LS.LSa.MuSa	Not Assessed	Intertidal mudflats	Carmarthen Bay and Estuaries	Estuaries; Mudflats and sandflats not covered by seawater at low tide
Polychaete/amphipod-dominated fine sand shores	LS.LSa.FiSa	Not Assessed	Not Section 7	Carmarthen Bay and Estuaries	Estuaries; Large shallow inlets and bays

2. Barrier to species movement

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 Shellfish using Trestles or Poles’;
- Select the pressure ‘barrier to species movement’; 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 Taf 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:

- Carmarthen Bay and Estuaries SAC;
- River Tywi SAC;
- Carmarthen Bay Special Protection Area (SPA); and
- Taf Estuary Site of Special Scientific Interest (SSSI).

The protected fish species in the vicinity of the proposed aquaculture site have a high sensitivity to the barrier to species movement pressure in the Natural England (2022) sensitivity assessment, including Allis and Twaite Shad, River and Sea Lamprey. Non-breeding Common Scoter, a feature of the Carmarthen Bay SPA, has been assessed as having a medium sensitivity to the pressure barrier to species movement. Please see the AWAA Final Report to understand the process of how confidence was assigned by Natural England to the sensitivity scores. The pressure was not considered relevant to Otter in the Natural England (2022) sensitivity assessment. 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 the Taf 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 ‘barrier to species movement’ using the example location of the Taf Estuary and the aquaculture activity of growing intertidal shellfish using trestles or poles. 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
Allis shad	*Alosa alosa*	High [High conf.]	Yes	Carmarthen Bay and Estuaries SAC; River Tywi SAC; Taf Estuary SSSI
River lamprey	*Lampetra fluviatilis*	High [High conf.]	Yes	Carmarthen Bay and Estuaries SAC; River Tywi SAC
Sea lamprey	*Petromyzon marinus*	High [High conf.]	Yes	Carmarthen Bay and Estuaries SAC; River Tywi SAC
Twaite shad	*Alosa fallax*	High [High conf.]	Yes	Carmarthen Bay and Estuaries SAC; River Tywi SAC; Taf Estuary SSSI
Common scoter (non-breeding)	*Melanitta nigra*	High [Medium conf.]	No	Carmarthen Bay SPA
Otter	*Lutra lutra*	Not relevant	Yes	Carmarthen Bay and Estuaries SAC

Intertidal Shellfish Aquaculture using Trestles or Poles

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 shellfish aquaculture using trestles or poles identified in Step 2 (Table 1) are provided below. The evidence summaries for the two pressures used in the Taf Estuary case study example in Step 4 are provided below in sections 3 and 15.

1. Above water noise

Although no evidence was found in the scientific literature for this pressure with respect to intertidal shellfish aquaculture using trestles or poles, above water noise is expected to occur during collection of shellfish, construction, maintenance 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 from intertidal shellfish aquaculture using trestles or poles can occur from the collection of mussel seed, installation of infrastructure, and the movements of vehicle or farm personnel between cultivation structures.

The collection of seed stock 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 scaring 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 in seed collection areas, for example, directly causing damage to species, changing turbidity or smothering (Forrest et al, 2009).

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

The trestles and poles used in this activity have the potential to act as a barrier to protected species that use the intertidal zone for foraging, transiting and hauling out, such as seabirds, otters, fish species or seals.

A study by Marine Institute and Atkins Ecology (2012) showed that species who tend to feed in large flocks of in tightly packed groups such as knot, sanderling, dunlin, black-tailed godwit and bar-tailed godwit, and to a lesser extent ringed plover can be negatively affected by oyster trestles which could interfere with flocking behaviour. The avoidance behaviour by these species was attributed to the trestles making it more difficult for large flocks to remain in contact as they become dispersed. It was noted that grey plovers showed a particularly strong negative response, potentially due to complex territorial behaviour. Waders which tend to feed in small flocks, such as turnstones, or widely dispersed individuals and loose flocks, such as oystercatchers, curlew, greenshank and redshank, showed a neutral to positive response to oyster trestle presence (Marine Institute and Atkins Ecology, 2012).

Other studies have in general 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).

It is likely that other species using the intertidal zone may be impacted by the presence of shellfish aquaculture infrastructure, for example, seals which haul out on the shore or foraging otters, however, no direct mention of this was found in the scientific literature. When considering a location for an aquaculture activity, it would be useful to identify any potential seal haul out sites in close proximity and assess whether the activity could disturb or displace seals.

Migratory fish species are potentially highly sensitive to barriers in the sea. It is unknown whether intertidal aquaculture would act as a barrier to the migration of protected fish species. The barrier effect would depend on the infrastructure and scale of the proposed activity.

4. Changes in suspended solids (water clarity)

Collection of seed mussel 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 bird species to collide with aquaculture structures above water in the intertidal zone during low tides or with vessels collecting mussel seed. However, no evidence was found in the scientific literature relating to the collision of species above water with intertidal shellfish aquaculture using trestles or poles. It is likely that any such instances would be relatively rare.

6. Collision BELOW water with static or moving objects

There is the potential for species to collide with intertidal aquaculture structures below water during high tides or with vessels during 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.

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 shellfish aquaculture using trestles or poles.

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.

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 or 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. 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 intertidal may be occupied with infrastructure.

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 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 bags and ropes 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. There is also the potential for parasites 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 the aquaculture of bivalves. 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 United States (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, bags and ropes can pose a significant entanglement 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. An example of how far aquaculture litter can travel was illustrated by Strietman et al. (2020) who found aquaculture-related litter from ‘Bouchet’ culture, used regularly in Normandy and France, along the Belgian, Dutch and German coastlines.

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. 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.

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

The use of dredges, for example, for 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. However, penetration and/or disturbance of the substrate below the surface of the seabed could result from trestles or poles being driven into the substrate to anchor infrastructure (ICES, 2020). 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. For example, ICES (2020) stated that in France, pole farms (Bouchot culture) can consist of 15,000–20,000 poles, therefore the larger the footprint the greater the potential impact.

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). For example, a study by Laffargue et al. (2006) found that the presence of oyster bags or trestles led to increase presence of fish, such as sole (*Solea solea*), compared to a homogenous seabed. It was suggested that the aquaculture infrastructure offered cover, camouflage and increased safety from predators. This potential change would depend on the scale and duration of the aquaculture operation.

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.

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).

18. 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 thought to be an issue for this particular aquaculture activity unless slack lines are involved in the trestle infrastructure.

19. 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).

20. Smothering and siltation rate change (light deposition)

Dredging and construction operations may redistribute and suspend sediment into the water column, leading to potential smothering of benthic habitats and species. 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. 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 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). 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.

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).

Forrest et al. (2009) state that compounds such as hypochlorite and acetic acid have been used in shellfish aquaculture to mitigate the effects of biofouling. However, these substances tend to be non-persistent contaminants which are unlikely to lead to significant non-target effects. Forrest et al. (2009) also note that historically, oyster cultivation racks have been constructed from wood treated with preservatives (e.g. copper–chromium–arsenic, CCA; creosote) that could leach into surrounding waters. This will be less of an issue with the use of modern metal trestle and poll infrastructure.

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. However, 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. 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.

25. Visual disturbance

Visual disturbance can occur by vessel/vehicle or personnel movement directly related to the collection and cultivation practices associated with intertidal shellfish aquaculture using trestles or poles. 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).

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, however, 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 intertidal 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).

26. Water flow changes

Bivalve aquaculture structures, such as trestles or poles with bags, baskets, lantern nets or lines, can cause drag and alter hydrodynamic processes within an area (ICES, 2020), however the impacts will be influenced by local hydrodynamic conditions and the design of the farm. The presence of structures can alter the direction of flow within an area, reduce current speed, dampen wave action and increase turbulence (Forrest and Hopkins, 2017; ICES, 2020). Kaiser et al. (1998) reported that the hydrodynamic changes caused by large numbers of trestles could lead to changes in sedimentation rate and oxygen exchange. Similarly, Forrest and Creese (2006) stated that culture racks can lead to enhanced sedimentation beneath the racks compared with other sites. They found that the seabed elevation beneath racks tended to be lower than between them, suggesting that topographic patterns likely result from the local effect of rack structures on hydrodynamic processes than from enhanced deposition. In addition, Forrest and Creese (2006) found that seabed sediments within farms had a greater silt/clay and organic content, and a lower redox potential and shear strength than sites with no farms. McKindsey et al. (2011), Desroy et al. (2011) and Grant et al. (2012) also report water flow changes and impacts to sedimentation/siltation rates.

Bouchet and Sauriau (2008) state that the presence of trestles reduces current velocities by 25% and favours the accumulation of biodeposits enriched in organic matter; this in turns leads to the impoverishment of oxygen levels within the sedimentary matrix.

27. Wave exposure changes

There is relatively little evidence in the literature regarding the impacts of wave exposure changes with intertidal shellfish aquaculture using trestles or poles. However, it is possible that infrastructure used for this activity has the potential to dampen wave action and have an impact on local coastal processes (McKindsey et al., 2011; ICES, 2020). It could be expected that a reduction in wave exposure has the potential to alter species communities by favouring species which are more tolerant of more sheltered conditions.

Intertidal Shellfish Aquaculture using Trestles or Poles

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 shellfish using trestles or poles 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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