Closing the Circle Report I: Aquaculture Opportunities for Enclosed Marine Water Bodies – Tidal Lagoon Swansea Bay Case Study

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FOR: MUMBLES OYSTER COMPANY LTD.

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AUTHORS NOTE AND DISCLAIMER

This study has been undertaken on behalf of the Mumbles Oyster Company Ltd. and is funded by the Strategic Investment Programme (SIP) of the Sea Fish Industry Authority (Seafish). This study is intended to assist in the formulation of a blueprint for development of mariculture in a tidal lagoon. The views expressed in this report are those of the Authors and are not therefore necessarily representative of the Mumbles Oyster Company Ltd. or the Sea Fish Industry Authority. The Authors as individuals or as Aquafish Solutions Limited and Salacia-Marine cannot be held responsible for any consequences arising from the use of this Report.

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*Section 5 also includes work by Dr Philip Kerrison and Dr Adam Hughes at SRSL.

RECORD OF STUDY DEVELOPMENT

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FD1.0	15 December 2016	Final Draft – Version 1.0 – Sections 1 to 10 + Matrix + Exec. Summary	ASL/SM
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FD3.0	13 January 2017	Final Draft – Version 3.0 – Sections 1 to 10 + Matrix + Exec. Summary (incorporating feedback from Seafish)	ASL/SM
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FD5.0	22 March 2017	Final Draft – Version 5.0 – As Ver FD4.0 + Spatial planning Section + feedback from TLSB	ASL/SM
FD6.0	23 March 2017	Final Draft – Version 6.0 – As Ver FD5.0 + feedback from TLSB	ASL/SM
FR1.0	24 March 2017	Final Report – Version 1.0 –	ASL/SM

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EXECUTIVE SUMMARY

AQUACULTURE OPTIONS WITHIN ENCLOSED WATER BODIES

- The current report provides an overview of aquaculture species and techniques that could be considered in marine enclosed water bodies such as ports, natural lagoons, artificial lagoons, estuaries, sea lochs as well as managed retreats.

- The proposed Tidal Lagoon Swansea Bay is presented as a case study. The Government commissioned Hendry Review has recommended that TLSB should be supported by Government as a pathfinder project. As TLSB has previously committed to including aquaculture within the lagoon, this therefore increases the potential for a first commercial example of co-location of offshore marine renewable energy operations with aquaculture.

- In terms of the case study, the species reviewed are those considered to be most economically viable in terms of commercial production, pose the least environmental impact and are in keeping with the wider aspirations of Tidal Lagoon Swansea Bay with regard to restoring native shellfish species such as *Ostrea edulis*.

- The delay in any final decision about whether the proposed lagoon in Swansea Bay will go ahead has significantly impacted operational planning by TLSB and therefore their ability to provide detailed spatial and operational information. Whilst the tidal rises and falls within the lagoon and relative extents of the inter and subtidal ranges will remain similar to baseline, the final layout of other facilities, such as for recreation, are yet to be confirmed which makes it impossible at this stage to describe in detail the placement of suspended mariculture cultivation activities.

- The overview of aquaculture species and techniques presented supports the more detailed spatial planning analysis presented in the Matrix comparative assessment of species and techniques vs. environmental and physical characteristics of the case study site.

ENVIRONMENT

- Swansea Bay is a hyper-tidal environment with a tidal range approaching 8.5 m on a mean spring tide and with an associated neap range of approximately 4 m. With the exception of the immediate vicinity of the turbine and sluice housing where flows will reach greater speeds, current speeds within the proposed lagoon site would be up to 0.4 m per second in the southern area of the lagoon and up to 0.2 m per second in the north-east area of the lagoon.

- Modelling of wave action shows that wave height within the lagoon would decrease significantly, thereby making it a relatively sheltered area with a strong potential for aquaculture operations.

- The seabed area within the proposed tidal lagoon is characterised by gravel to the west and south of the site and sand with varying amounts of gravel to the north and east of the site.

- The proposed 1.5 km main sewage outfall extension would result in E. coli levels within the lagoon of between 0 to 500 per 100 ml of seawater resulting in a Shellfish Classification of between A to B, considered suitable for bivalve shellfish and seaweed cultivation.

CULTIVATION SUMMARY

- The comparative Matrix assessment provides a detailed analysis of the physical, environmental and technical variables underpinning the cultivation opportunities for individual aquaculture species within the proposed tidal lagoon in Swansea Bay.

- The detailed Matrix assessment is presented in an Excel format. A summary of the main findings taken from the Matrix are shown overleaf.

Invertebrate Species	**Method of Feeding**	**Production Method**	**Technical Feasibility**	**Risk Levels - Environmental**
Baseline Lagoon Conditions	NA	NA	How likely is it that this species and technique could be successfully carried out based on available info.?	Qualitative summary of likelihood of successful culture given combined constraints and environmental factors.
General Conditions for bottom cultured bivalves (containment)	NA	Bag & trestle, baskets etc.	**High**	**Low**
General Conditions for bottom cultured bivalves (ranching)	NA	On bottom, under predator netting	**Moderate (Species specific)**	**Moderate (Species specific)**
General Conditions for Suspended bivalves	NA	Mussel lines, lantern nets etc.	**Moderate (Species specific)**	**Moderate (Species specific)**
Blue Mussel, ***Mytilus edulis***	Suspension	Bouchot poles	**High**	**Low**
	Suspension	Bottom culture	**Moderate**	**Moderate**
	Suspension	Suspended ropes	**Low/Moderate**	**Moderate**
Native Flat Oyster, ***Ostrea edulis***	Suspension	Intertidal Trestles/Baskets	**High**	**Low**
	Suspension	Bottom culture	**Moderate**	**Moderate**
	Suspension	Suspended nets/cages	**Moderate**	**Moderate**
Pacific Oyster, ***Crassostrea gigas***	Suspension	Intertidal Trestles/Baskets	**High**	**Low**
	Suspension	Bottom culture	**Moderate**	**Moderate**

Invertebrate Species	**Method of Feeding**	**Production Method**	**Technical Feasibility**	**Risk Levels - Environmental**
	Suspension	Suspended nets/cages	**High**	**Low**
King Scallop, ***Pecten maximus***	Suspension	Bottom culture	**Low**	**Moderate**
	Suspension	Suspended culture e.g. lantern nets	**Low**	**Moderate**
European Clam, ***Ruditapes decussatus***	Suspension/Deposit	Intertidal bottom culture	**High**	**Moderate**
Cockles, ***Cerastoderma edulis***	Suspension	Intertidal bottom culture	**Low (Currently)**	**High**
Macroalgae				
***Porphyra* spp.**	NA	Trestles/Nets/ Ropes/Lagoon wall	**High**	**Moderate**
***Laminaria* spp.**	NA	Suspended systems/Lagoon wall	**High**	**Moderate**
***Ulva* spp.**	NA	Nets/Ropes/ Lagoon wall	**High**	**Moderate**

MACROALGAE CULTIVATION

- The intertidal area, subtidal area and the tidal breakwater are all potential areas within the proposed lagoon that could be used for seaweed cultivation.

- Porphyra is considered to be a good candidate for cultivation within the proposed lagoon. Porphyra grows as thin, fast growing sheets and is tolerant to very high light levels and desiccation.

- Porphyra is a high value seaweed and is used to make nori sheets, Welsh laverbread and as an ingredient in value added products such as processed snacks. There is both and local and national market for this product that would benefit from what should be a strong market brand.

- Pilot-scale cultivation trials will be necessary to determine how well Porphyra would grow within the lagoon. Physicochemical characteristics of the water body as well as turbidity levels, in terms of light penetration, and suspended solid levels, in terms of the potential for smothering, will all need to be determined.

BIVALVE CULTIVATION

- The comparative Matrix assessment indicates that the proposed lagoon would be a suitable site for cultivation of a range of bivalve shellfish species in both the intertidal and subtidal zones.

- No detailed information is currently available regarding the relative size of the intertidal and subtidal zones and therefore spatial availability for mariculture activities cannot be assessed.

- The potential Class A Shellfish Classification would give Food Business Operators using the lagoon an advantage in terms of reduced post-harvest processing requirements; more ready access to the retail multiples; marketing/branding advantages.

- Pilot-scale bivalve shellfish cultivation trials would initially be required in order to assess system performance and species performance in terms of mortality, growth rates and condition.

SPATIAL PLANNING TOOLS FOR AQUACULTURE

- Spatial planning tools for aquaculture can help to support decision making for managers or prospective farm developers.

- The current report describes both regional level and site level examples in Wales of where aquaculture might be sited both at present or, potentially in the future as technology, operational practises or the economics of production change.

- Whilst spatial planning tools and analyses offer much to managers, regulators and developers, they may face limitations where data is unavailable or inaccessible.

- Milford Haven Port Authority is developing an ambitious project entitled Aquacoast with academic partners in the UK and Ireland and is aimed at addressing these data gaps and developing a range of spatial models that include economic analysis. The project's aim is to support sustainable aquaculture development in Ireland and Wales, mitigating risk and increasing the attractiveness to aquaculture and ancillary businesses.

- The web-based mapping tools developed for the Marine Plan projects in the UK's devolved administrations may offer an opportunity for further development of tools to assist aquaculture development. These are "live" sites and there may be an opportunity to develop, at a site level, more detailed layers and use these sites as a planning tool at that level.

- Spatial planning tools may not be necessary for sites such as tidal lagoons as these are essentially a blank canvas for development. Spatial analyses for lagoons will focus more on identifying applicable areas for individual aquaculture species/techniques.

AQUACULTURE PARK CONCEPT

- To date, there have been very few examples of co-location between the marine renewable energy and aquaculture sectors.
-
- The proposed lagoon in Swansea Bay being developed by TLSB offers an important opportunity to demonstrate that co-location of marine renewable energy and aquaculture is both feasible and practical. An 'Aquaculture Park' approach is presented within the current study as a means by which co-location might be successfully achieved.
-
- In this study an 'Aquaculture Park' is defined as a working relationship whereby the main stakeholder (marine renewable energy sector), is granted the licence to undertake a secondary mariculture co-location activity within the spatial footprint of the marine renewable energy site, together with the right to sub-let the licensed areas

for the co-location activity to selected specialist partner organisations, whilst providing specific services to those partner organisations.

- The provision of services by the main stakeholder allows them to retain control over and input into other commercial activities taking place within its spatial footprint. Importantly, this should help to provide confidence to the main stakeholder that its core operations will not be adversely impacted by the secondary co-location activity.

- Services provided by the main stakeholder could include the provision of high quality aquaculture equipment maintained under defined service schedules; hire facilities for high cost capital assets such as aquaculture service vessels; co-operative on-shore facilities; central administration of all licensing and permissions including Shellfish Classifications, Biosecurity Management Plans, Aquaculture Production Business licence; environmental monitoring.

- The Aquaculture Park approach provides a blueprint for how marine spatial resources within offshore marine renewable energy sites can be most efficiently utilised for individual commercial organisations as well as the wider Welsh economy.

- The Aquaculture Park approach would provide the following:
  - A marine licensing framework for aquaculture activities within offshore marine renewable energy sites;
  - Through the provision of services, reassurance to marine renewable energy operators that conflicts with other users can be avoided and that core energy production operations are protected;
  - Provide practical solutions to carrying out mariculture operations in enclosed water bodies;
  - De-risk and fast track new mariculture operations thus helping to increase the chances of attracting inward investment or funding.

SECTION 1 – CO-LOCATION WITHIN MARINE ENCLOSED WATER BODIES

1.1 Co-location of Aquaculture and Marine Renewable Energy

There are strong drivers for expanding aquaculture production in the UK. These include food security, population health benefits through the consumption of seafood, improved environmental sustainability and increased socio-economic activity. The Welsh Government is also committed to doubling production of both shellfish and finfish aquaculture by 2020 (Ref: Welsh Government, 2013). In addition, there is increasing interest in the cultivation of macroalgae as both a food product and potentially as a bulk commodity for the pharmaceutical, cosmetic and biofuel sectors although the economic viability of this type of cultivation within UK waters has yet to be proved.

Co-location of aquaculture with other marine activities, such as renewable energy, would seem to make the most efficient use of what appears to be an ever-decreasing marine spatial resource (Ref: Mee and Kavalam, 2006). Certainly, in terms of co-location there is an opportunity within Welsh waters and wider UK waters to take a global lead in developing forms of aquaculture that are compatible with marine renewable energy operations (Ref: Syvret *et al.*, 2013).

1.2 Aquaculture in Marine Enclosed Water Bodies

The priority and focus of this report is twofold:

1. To present an 'Aquaculture Blueprint' that might be considered in terms of the successful co-location of offshore marine renewable energy sites and mariculture activities taking into account the particular issues posed with respect to marine licensing.

2. To describe aquaculture techniques and potential candidate shellfish and macroalgae species that might be considered in marine enclosed water bodies. Examples of enclosed water bodies include ports, natural lagoons, artificial lagoons, estuaries, sea lochs and could also include managed retreats.

It is important to note with respect to Point 2 above that the species reviewed are those considered to be most economically viable in terms of commercial production.

1.2.1 Tidal Lagoon Swansea Bay - Aquaculture Blueprint and Hatchery Design

This report will highlight the potential mariculture options, in terms of species and techniques that might be considered in co-location activities that are compatible with tidal lagoons using the proposed Tidal Lagoon Swansea Bay (TLSB) as a case study. In considering the proposed marine tidal lagoon in Swansea Bay, these species and techniques are also those that are considered to have the least environmental impact and that are in keeping with the wider aspirations of TLSB in terms of restoring native shellfish species such as *Ostrea edulis*. Finfish culture was initially considered, but the shallow residual depth of the lagoon at extreme low tides, relatively small available footprint plus the likely environmental and visual impact of cage culture were considered by the Authors to make this type of aquaculture incompatible with the proposed lagoon.

As described in Section 1.2 above, any mariculture operations within the proposed lagoon would be carried out by commercial Food Business Operators (FBOs) and must therefore be economically viable i.e. return a profit through normal operations. In terms of species and techniques reviewed therefore, by way of an example, the current report considers species such as the king scallop, *Pecten maximus*, but does not include the smaller queen scallop, *Aequipecten opercularis*, due to the far lower market value of the latter species (Source: Marine Management Organisation).

During the course of the current project, TLSB highlighted the potential of the rock armour of the proposed lagoon as a site for lobster restocking. In practical terms, in the view of the Authors, the specialist nature of lobster hatchery production means that rather than trying to produce juveniles on-site, TLSB should consider partnership arrangements or projects with organisations such as the National Lobster Hatchery (Padstow, Cornwall). This type of arrangement might provide juveniles that would help to enhance what is likely to be natural recruitment of lobsters over time, although, at least at present, there isn't an economic argument for considering lobsters as a species for aquaculture.

The types of mariculture activities considered in this report are a mixture of intertidal techniques (e.g. Pacific oyster cultivation in bags on trestles, native clams under mesh), and subtidal techniques (e.g. seabed and suspended fixed gear cultivation of mussels or oysters) and could be applied to any of the enclosed water bodies with the correct environmental and physical characteristics.

The present study also considers the development of an on-shore shellfish hatchery with associated microalgae cultivation. It is suggested that the shellfish hatchery should be operated in association with the proposed spatting ponds due to their potential multiple other uses such as blooming ponds for large-scale microalgae production, nursery system for on-growing seed shellfish etc. A *Generic Hatchery Design* forms a separate deliverable under the current study.

Progress Report 1 (dated July 2016) of the Aquaculture Blueprint describes the Matrix approach to scoping potential mariculture species and techniques with cross comparison to the main environmental variables. This work is summarised in Section 2. Sections 3, 4 and 5 of the current report give a general overview of the main species and techniques that might be considered for mariculture operations within a tidal lagoon. Sections 7 and 8 review production scenarios, costs, production levels, markets and partners for the differing mariculture products and techniques. Section 6 reviews the development and use of spatial planning tools to support aquaculture development including a case study for an enclosed water body.

1.2.2 Shellfish Hatchery and Spatting Ponds

Tidal Lagoon Swansea Bay (TLSB) received a Developmental Consent Order (DCO) in June 2015 for the proposed tidal lagoon in Swansea Bay. The 9.5 km Lagoon wall starting at the eastern side of the River Tawe will enclose an 11.5km^2 area of sheltered water. Figure 1 shows the proposed location of the lagoon.

Figure 1: Proposed location of the tidal lagoon within Swansea Bay (Source: Tidal Lagoon Swansea Bay)

A review of tidal energy in the UK (Hendry Review https://hendryreview.wordpress.com/) presented its findings in January 2017. One of the main recommendations of the review is that the Government should support the construction of a tidal lagoon in Swansea Bay as a 'pathfinder' project to investigate the potential of tidal energy and "*so the learning opportunities it offers can be maximised"*. A strike price for the electricity generated from the lagoon is required between the developer and UK Government in order for the Project to proceed.

As part of the Developmental Consent Order (9th June 2015), there are a number of legal requirements placed upon TLSB. Included within this are target trawls for native oysters from the footprint of the lagoon. This DCO, together with a section 106 agreement (8th December 2014), also places upon TLSB a requirement to provide "hatcheries and laboratories together with oyster spatting ponds", the latter as part of a programme to encourage the reintroduction of the native oyster to Swansea Bay.

The potential long-term development of a shellfish, and possibly macroalgae, hatchery is to be welcomed. There is a need at present for the UK shellfish cultivation sector to have access to a secure supply of disease free seed if commercial shellfish mariculture operations are to be developed and be successful at this site or others around the UK. This need has been reiterated recently by Hambrey and Evans (Ref: 2016) in a report for the Sea Fish Industry Authority (Seafish) describing aquaculture in England, Wales and Northern Ireland. The plans for a hatchery development at the Swansea site offer a solution, potentially providing locally produced seed with the vital continuity of supply and biosecurity safeguards.

1.2.3 Aquaculture Case Study

The development of a tidal lagoon represents a new opportunity for mariculture activities. The current project considers spatial planning and economic overviews that will help in establishing the potential range of systems and species that might be grown commercially within a tidal lagoon or similar water body or area. The current report therefore describes spatial planning for aquaculture within the proposed tidal lagoon but also seeks to provide tools and information that might be of use more generally when planning new mariculture development opportunities.

From discussions with TLSB regarding the Swansea Bay Tidal Lagoon, the authors of this report are aware that there is a desire to balance nature conservation, watersports, recreation and aquaculture at the site (see Figure 2) and that large-scale highly industrialized operations may not be appropriate due to space limitations.

Figure 2: Artist's impression of the lagoon seawall and amenities following construction (Source: Atkins http://www.atkinsglobal.com/en-gb/projects/swansea-bay-tidal-lagoon)

This multi-functional use of the lagoon would indicate therefore that the focus for mariculture within the proposed lagoon should be on the culture of higher-value bivalve species and macroalgae, targeting a premium niche market in order to help ensure that the operations are economically viable from the relatively small footprint.

There may be scope for cultivation of certain shellfish species in the same spatial footprint as other activities where sufficient health and safety safeguards can be introduced and managed. There are wider aspirations for the restoration and reintroduction of the native oyster, *Ostrea edulis*, which could be achieved both through commercial production, termed 'Restoration Aquaculture' (Andy Woolmer, pers. comm.), as well as purely restorative activities.

The potential for high water quality in terms of microbial loading would lend the lagoon a practically unique status in terms of large-scale mariculture activities within England and Wales. Shellfish waters with an A Classification comprise only a very small percentage of areas under shellfish cultivation and provide an attractive site for bivalve shellfish cultivation including that of the native oyster (Ostrea edulis) a Biodiversity Action Plan (BAP) species. The native oyster restoration aims of TLSB are in keeping with another restoration initiative in this area instigated by the Mumbles Oyster Company Ltd.

1.2.4 Swansea Bay and the Tidal Lagoon Environment

Swansea Bay is a hyper-tidal environment with a tidal range approaching 8.5 m on a mean spring tide and with an associated neap range of approximately 4 m. Modelling shown in Figure 3 shows that with pumping at the end of the energy generation cycle the lagoon should exhibit similar, but offset, tidal extremes to that experienced outside the lagoon.

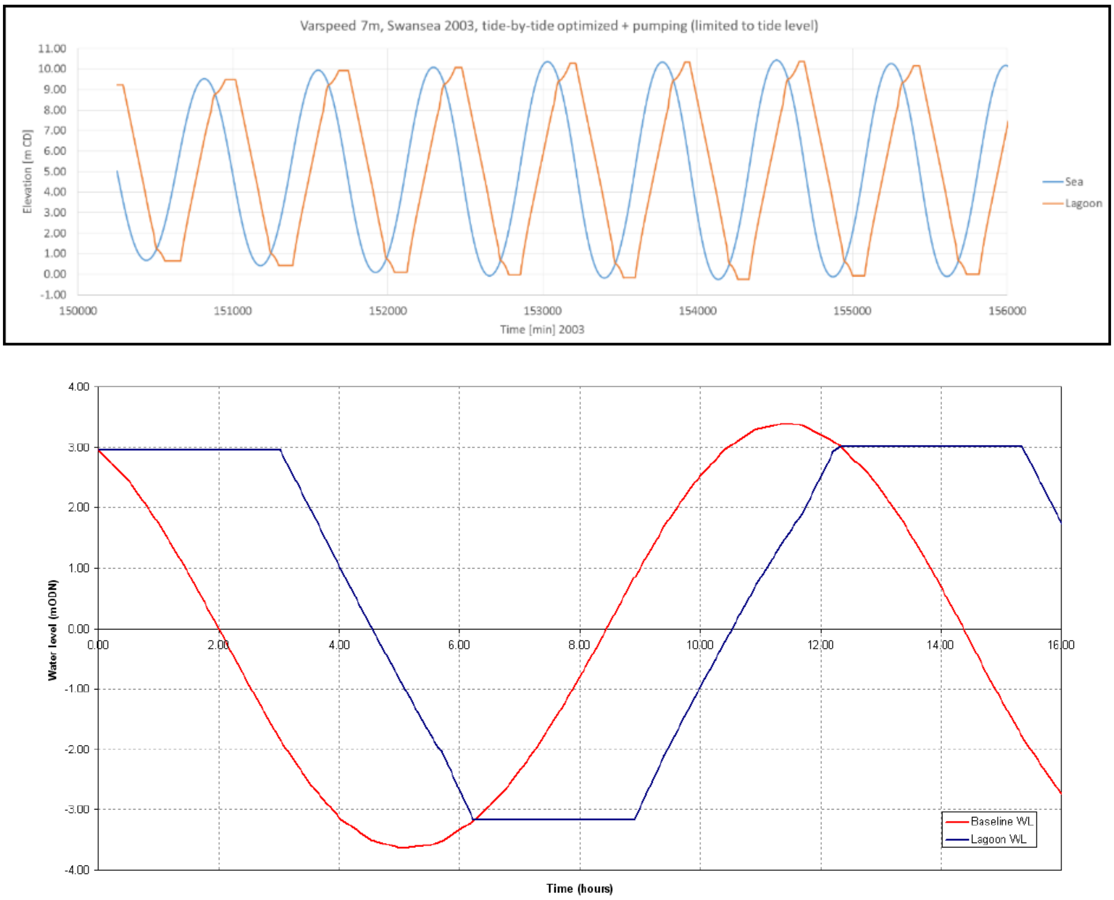

Figure 3: Predicted tidal extremes at high and low water following construction of the lagoon (Source: ABPmer www.abpmer.co.uk)

In terms of current speeds, modelling by ABPmer indicates that maximum flood flow speed on a spring tide will generally result in increased flows through the west, north and east of the site, compared to baseline, with a slight decrease in the extreme south of the site as shown in Figure 4. During mean spring tides, current speeds within the proposed lagoon site would be up to approximately 0.4 m per second in the southern area of the lagoon and up to 0.2 m per second in the northeast area of the lagoon (Source: ABPmer).

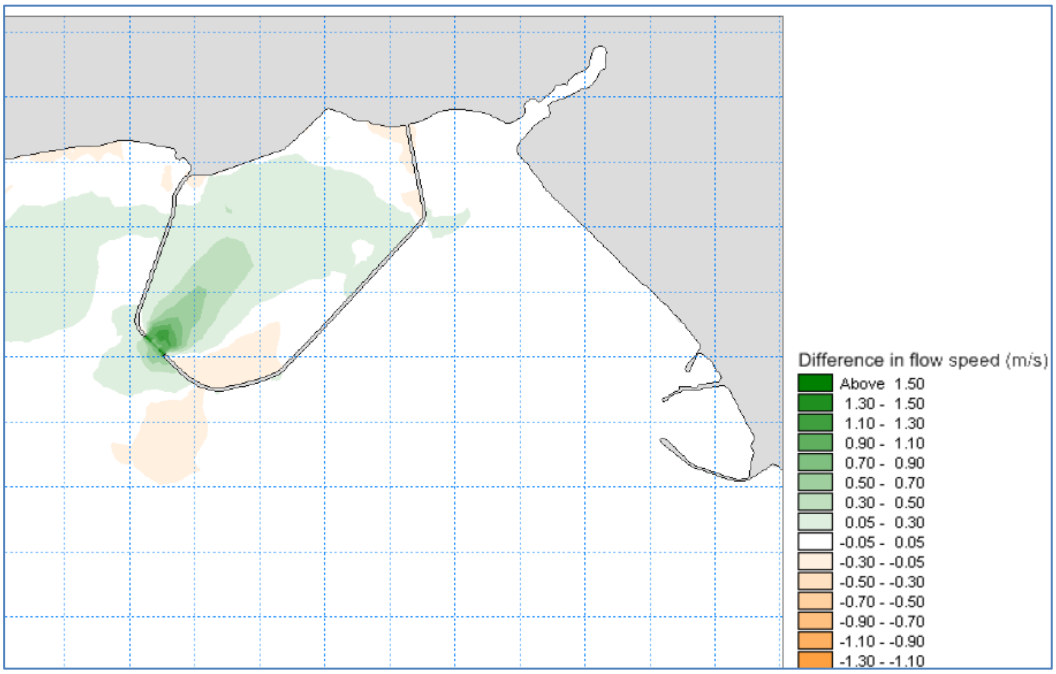

Figure 4: Difference in maximum flood tide flow speed within the lagoon (Source: ABPmer www.abpmer.co.uk)

Modelling of maximum ebb flow speeds (see Figure 5) show a small decrease in flow speeds compared to baseline across the lagoon site of around 0.05 to 0.30 metres per second with the exception of the area immediately inside the turbines to the south west of the site.

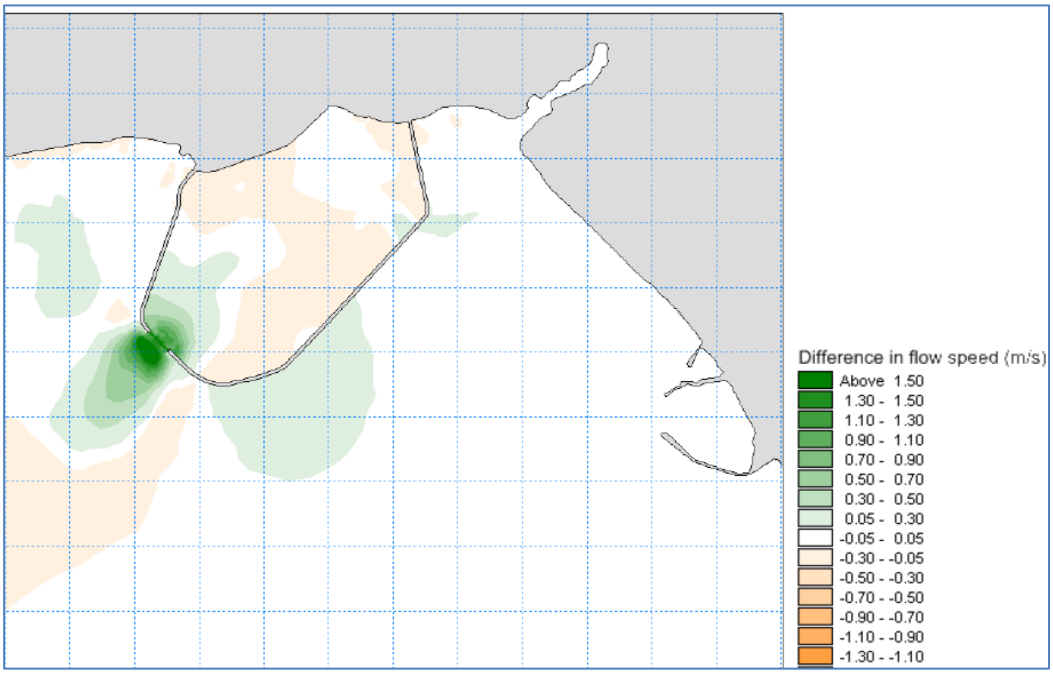

Figure 5: Water flow rates on an ebb tide following lagoon construction (Source: ABPmer www.abpmer.co.uk)

As shown in Figure 6, it is anticipated that residual tide flow within the proposed lagoon would be in a clockwise direction.

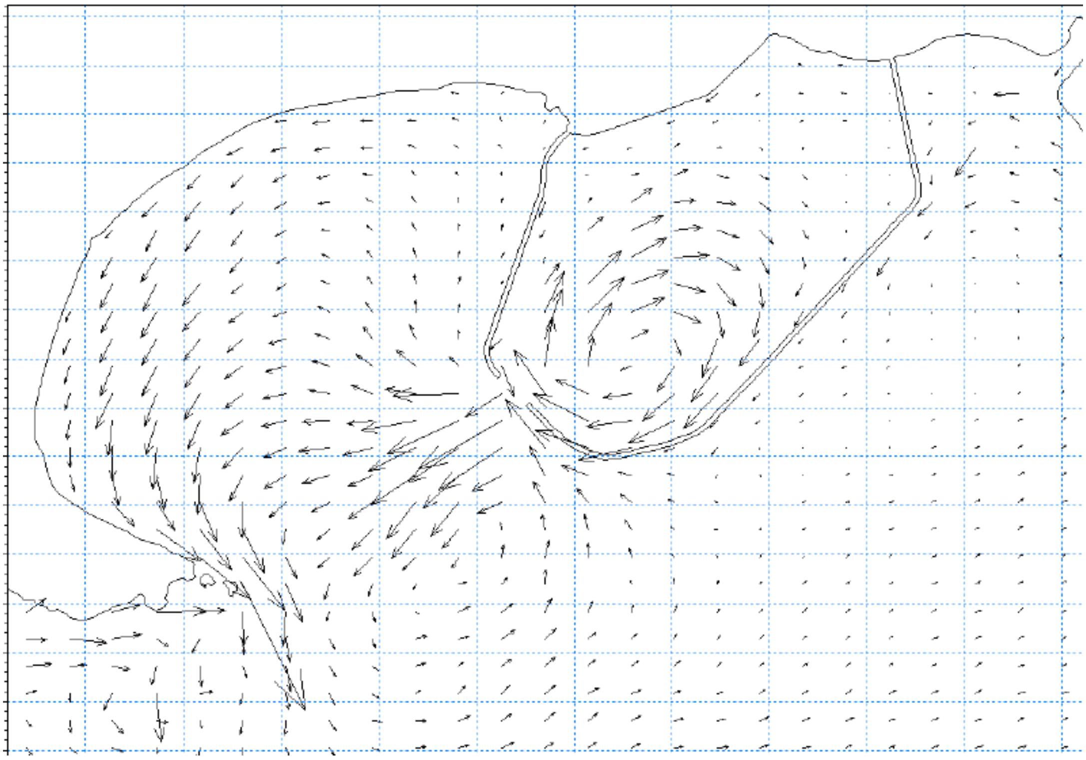

Figure 6: Residual tidal flow following lagoon construction (Source: ABPmer www.abpmer.co.uk)

Swansea Bay can experience large south-westerly waves originally formed in the North Atlantic with some coastal sheltering in the Mumbles area. The project metocean survey has recorded significant wave heights of up to 1.9 m within the site proposed for the lagoon (Source ABPmer). As would be expected, modelling carried out by ABPmer, showed a significant reduction in wave height within the lagoon under both south-westerly and south-easterly conditions (Figure 7). The reduction in wave heights was greatest closer to the lagoon wall with smaller reductions in wave height towards the shore.

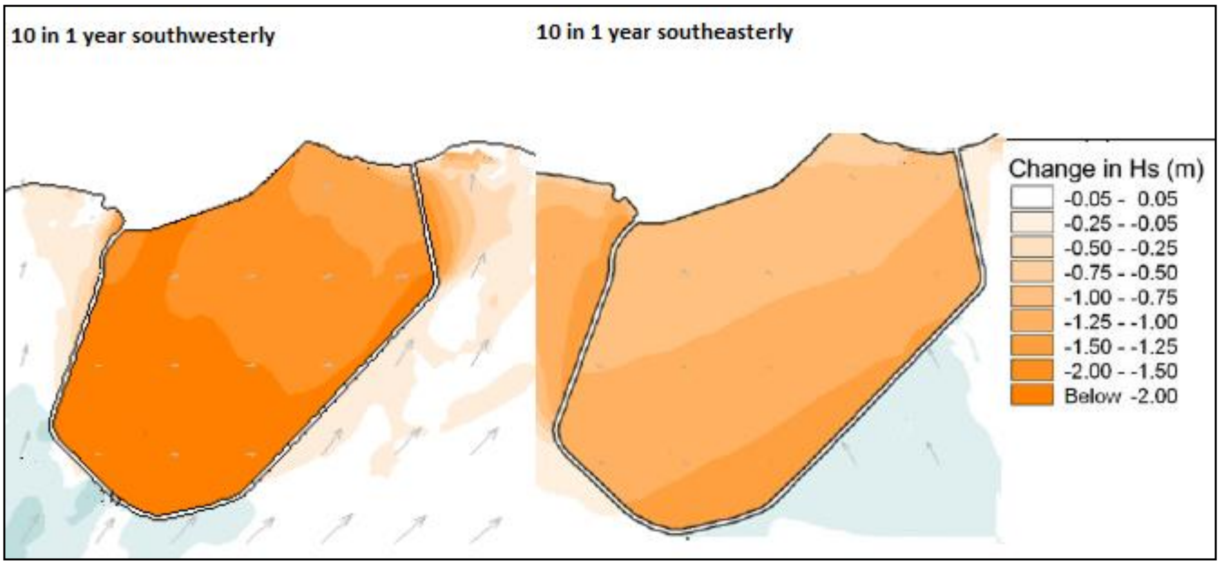

Figure 7: Predicted wave heights outside and within the proposed lagoon (Source: ABPmer www.abpmer.co.uk)

The seabed area within Swansea Bay proposed for the tidal lagoon is characterised by sediments consisting mainly of gravel to the west and south of the site (shown in Pink in Figure 8) and sand (shown in Yellow in Figure 8) with varying amounts of gravel to the north and east of the site (Source: ABPmer).

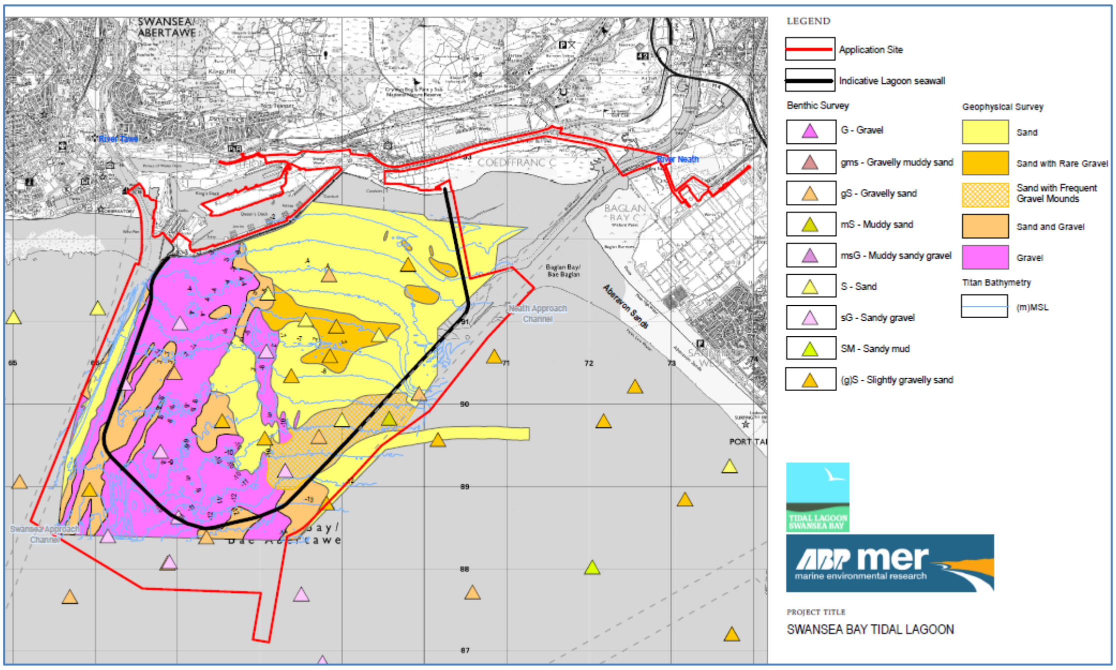

Figure 8: Seabed sediment distribution for the area within Swansea Bay proposed for a tidal lagoon (Source: ABPmer www.abpmer.co.uk)

In modelling carried out by ABPmer under various storm event scenarios, it appears that, in terms of mud transport (see Figure 9), there will be some increase in bed thickness mainly towards the north of the lagoon and in the south to a lesser extent (shown as Red/Orange in Figure 9), whilst to the west and east of the site, bed thickness will decrease (shown as Green in Figure 9). There are no predicted bed thickness changes associated with sand transport.

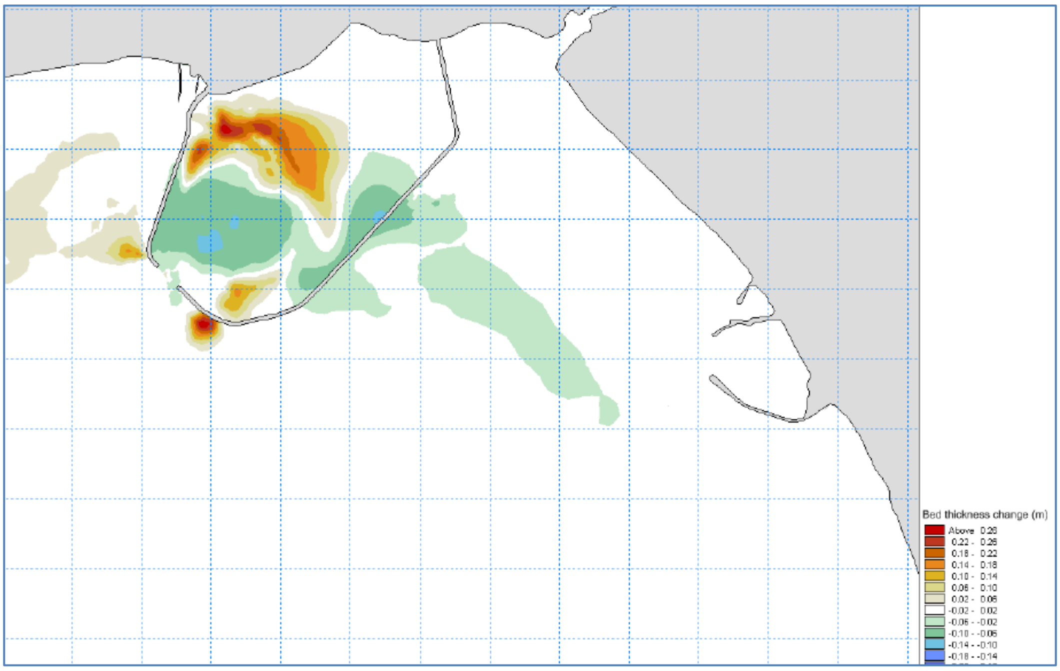

Figure 9: Modelling of mud transport following lagoon construction (Source: ABPmer www.abpmer.co.uk)

Due to Swansea's industrial past there is the potential for sediments in some areas to be contaminated (e.g. with heavy metals and man-made substances such as TBT and PCBs). Sediment quality data from the Swansea and Port Talbot approach channels and docks collected between 1995 and 2002 suggests that contamination levels are in a general decline. Analysis of sediment samples as part of the Lagoon project confirmed that approximately 75% samples were below the lower Cefas Action level 1 threshold, with the remaining being below action threshold 2, making all sediments fit for purpose for the Project. Whilst the presence of contaminants such as TBT are known to affect shellfish, all levels of TBT recorded within the proposed lagoon footprint were below Action level 1. In addition to this, maintenance dredging of new deposition within the lagoon would be unlikely to release contaminants trapped in older sediments and monitoring as part of future maintenance dredging marine licences will be carried out to confirm this.

1.2.5 Classifications and Shellfish Hygiene

Filter feeding bivalve molluscs have the potential to bioaccumulate microbial contaminants and algal toxins that can cause illness in humans. Of particular risk to human health are shellfish that are either eaten raw or lightly cooked, such as the oyster. Shellfish Classifications, originally drawn up under the Shellfish Hygiene Directive (SHD), provide public health protection from the consumption of shellfish which are accepted as being a potentially high risk food.

The use of *E. coli* levels in bivalve molluscs as an indicator for Classification of harvesting waters is readily justifiable on scientific grounds as the presence of *E. coli* is evidence of recent contamination by human sewage or animal faecal matter. If high levels of *E. coli* are recorded, then this can have very serious economic impacts on shellfish growers as they are then required to either re-lay by moving stock to cleaner water or heat treat the shellfish. In terms of the Classification system, where 'downgrades' in Classifications from B to C take place then ultimately this may put the shellfish farmer out of business as the extra work involved in re-laying, or the lower price received for heat treated shellfish, will often make the farm financially uneconomic to operate. Whilst many European countries have a high percentage of Class A waters where growers can sell direct to the market, in England and Wales these form only ~1 % of beds. This places UK businesses at a disadvantage compared to foreign imports as many major retail chains will only buy product from Class A waters. Shellfish from Class B waters require purification which involves both capital outlay for equipment and then an on-going operational cost (Ref: Syvret and Woolmer, 2015).

Issues concerning water quality are generally considered to be the biggest threat to the shellfish cultivation sector. As such water quality is a key determining factor in site selection for cultivation operations. Macroalgal or seaweed cultivation for human consumption will also have to consider hygiene and water quality when considering site selection.

At present, the site of the proposed lagoon is designated as a Shellfish Water (see Figure 10) and incorporates the Swansea waste water treatment work's (WwTW) discharge. The WwTW continually discharges tertiary treated (UV disinfected) final effluent and also intermittently discharges storm water.

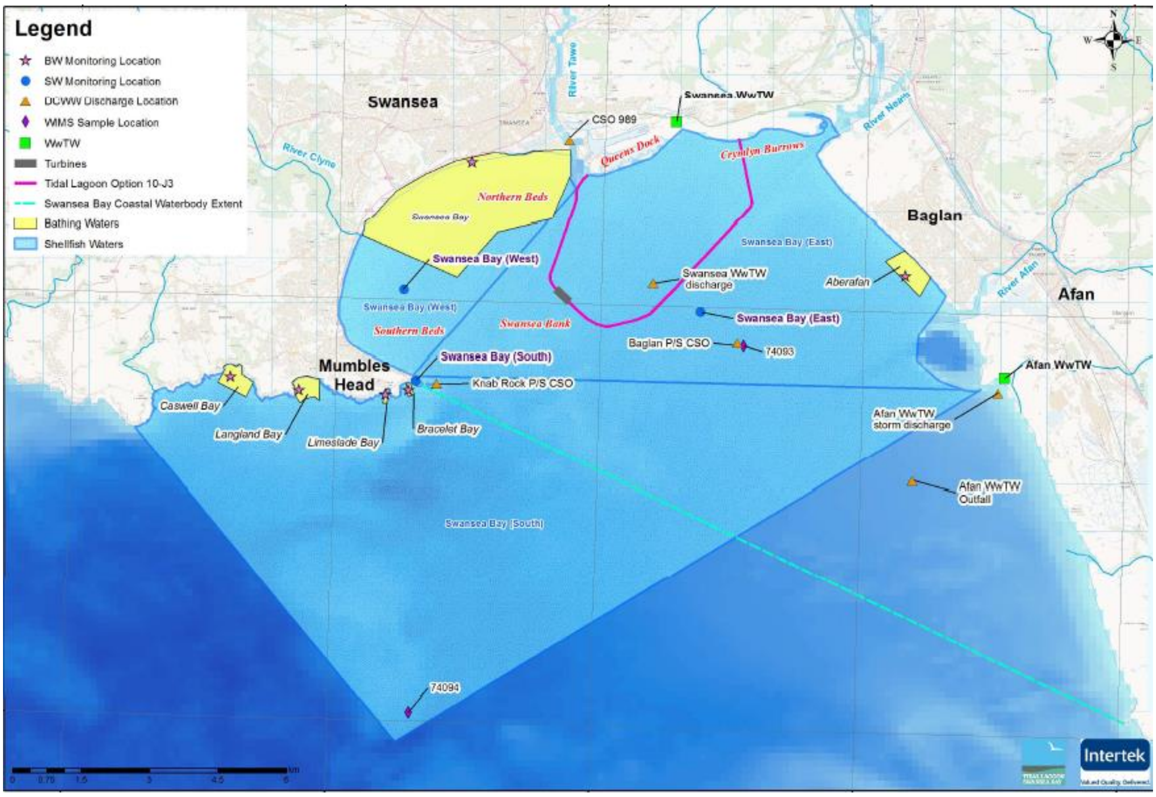

Figure 10: Waste water discharges within Swansea Bay (Source: Intertek www.intertek.com)

Modelling by Intertek (see Figure 11) indicates that if the lagoon were built without any mitigation in terms of microbial contamination from the intermittent storm water discharge, then *E. coli* concentrations are likely to be on occasion, between 2,000 to 10,000 *E. coli* per 100 ml of seawater.

The proposed 1.5 km outfall extension, which would take the outfall outside the lagoon, would result in *E. coli* levels of between 0 to 500 per 100 ml of seawater together with reductions in Nitrogen levels below the current baseline.

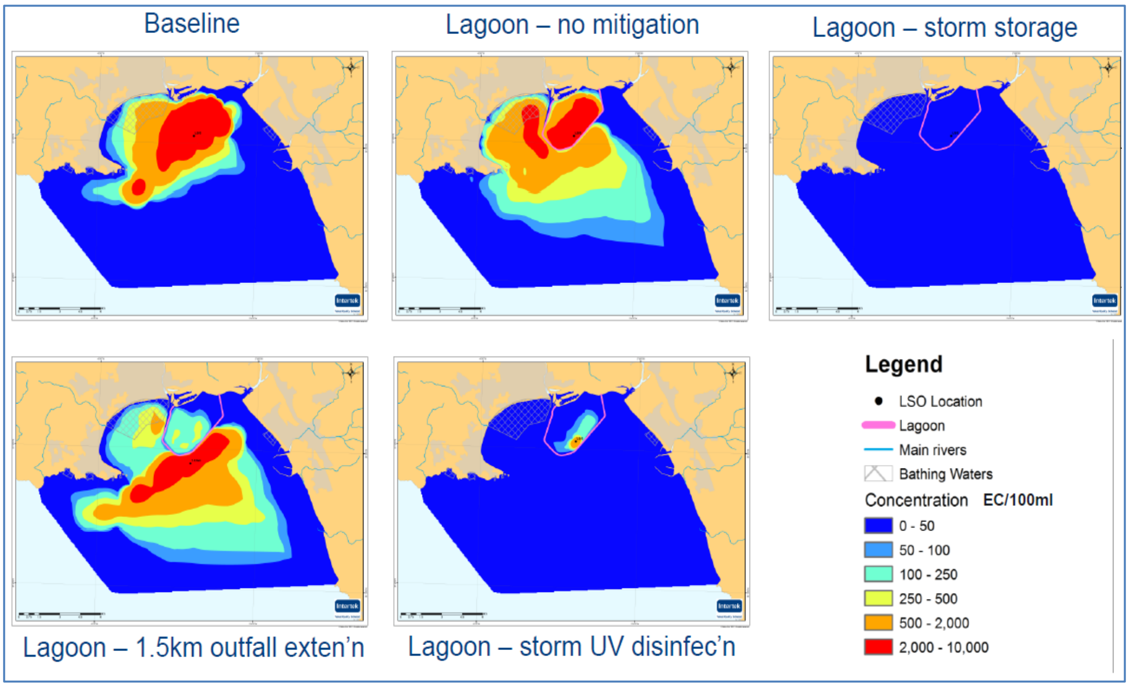

Figure 11: Modelling of 95 percentile E. coli conc.^{n} with continuous storm discharge (WwTW only) (Source: Intertek www.intertek.com)

The predicted *E. coli* levels would result in a Shellfish Classification of between Class A to Class B which would be suitable for production of bivalve shellfish. Further Intertek modelling of coastal water quality has shown that even with the waste water outfall still in place, there is unlikely to be a significant impact on Dissolved Oxygen levels. Figure 12 shows a worst-case scenario for Dissolved Oxygen levels with the outfall still in place, a neap tide, no wind, summer temperatures and maximum salinity.

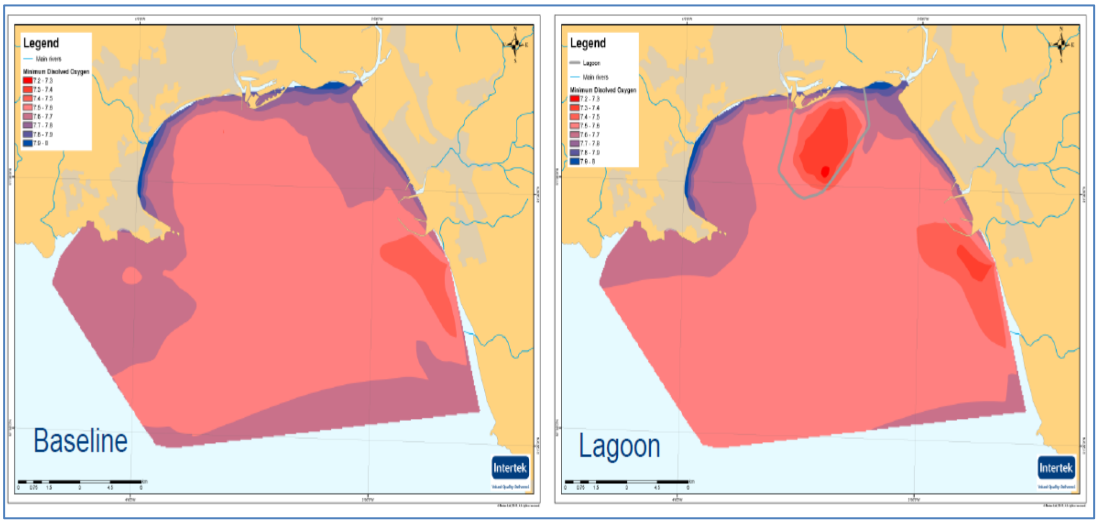

Figure 12: Modelling of Dissolved Oxygen levels before and after lagoon construction (Source: Intertek www.intertek.com)

The changes shown in Figure 12, even under a worst-case scenario, result in only a <5 % DO level decrease within the lagoon which would have no impact on shellfish aquaculture operations.

1.3 Summary

The modelling carried out by ABPmer and Intertek on behalf of TLSB indicates that, in general, the physical environment and water quality characteristics of the proposed lagoon would make it suitable for shellfish cultivation through aquaculture operations.

There is some potential for sediment accumulation once the lagoon is operational but the biggest increases in bed thickness are predicted to be in the north west of the lagoon which is most likely to be outside the area made available for aquaculture e.g. will be used for recreational use only.

Predicted *E. coli* levels of under 500 per 100 ml seawater mean that it is possible that Class A Shellfish Classifications could be obtained which would give aquaculture operators a distinct advantage in terms of both marketing and levels of post-harvest processing requirements.

As described in Section 1.2 it is likely that challenges to aquaculture production within the proposed lagoon will not be environmental or linked to water quality as in most production sites, but will be more to do with integrating the day to day operations of the aquaculture producers with the requirements of TLSB in terms of generating electricity. The current study therefore proposes an 'Aquaculture Park' approach to combat any perceived difficulties (see Section 9). The Aquaculture Park concept could provide a blueprint that should help to give confidence to TLSB that aquaculture and marine renewable energy co-location is not only possible but desirable whilst potentially providing aquaculture operators with fast track de-risked access to optimum production sites.

SECTION 2 – COMPARATIVE ASSESSMENT OF SPECIES VS. TIDAL LAGOON ENVIRONMENT

2.1 Matrix Overview

To help in the identification of possible mariculture species options and cultivation techniques within the case study of Tidal Lagoon Swansea Bay, an assessment of individual species environmental requirements was undertaken and compared to the likely range that will be encountered within the proposed tidal lagoon at Swansea Bay. In addition, a brief overview is also included of likely shore side facilities that will be required in order to allow practical and economic production of the proposed mariculture species and on-growing techniques.

To facilitate presentation a Matrix approach has been adopted in the current study. The advantage of a Matrix is that it allows the presentation and cross comparison of multiple variables in one output whilst facilitating interpretation for the reader. A 'traffic light' system is used to highlight the extent to which the species/technique are compatible with other variables i.e. where species, techniques etc. are thought possible (Green shading), unlikely or potentially risky (Orange shading) through to unlikely (Red shading). Where there is a degree of uncertainty, then an intermediate colour shading is used.

The output from the Matrix has provided a basis for further Operational Planning (Progress Report 2)

The variables that have been considered in the Matrix for bivalve shellfish and macroalgae are as follows:

- **Method of Feeding**
- **Production Method**
- **Temperature – air and sea surface (ºC)**
- **Salinity (PSU)**
- **Sediment Type (Bottom Culture)**
- **Wave and Tidal Exposure**
- **Depth**
- **Current Speed**
- **Chl a + POM/Nutrients**
- **Suspended Sediment/Smothering**
- **Turbidity Tolerance**
- **Hygiene requirements**
- **Key Risks, Constraints**
- **Technical Feasibility**
- **Risk Levels – Environmental**
- **Direct Shore Side Facilities Requirements**

The full Matrix is contained in a separate electronic document that forms part of this report and which is nominally recorded in Appendix 1.

2.2 Summary of Matrix Findings

A summary of the main conclusions reached through the Matrix investigation of potential aquaculture options in the proposed tidal lagoon at Swansea Bay is shown in Figure 13 overleaf.

Invertebrate Species	Method of Feeding	Production Method	Technical Feasibility	Risk Levels - Environmental
Baseline Lagoon Conditions	NA	NA	How likely is it that this species and technique could be successfully carried out based on available info?	Qualitative summary of likelihood of successful culture given combined constraints and environmental factors.
General Conditions for bottom cultured bivalves (containment)	NA	Bag & trestle, baskets etc.	**High**	**Low**
General Conditions for bottom cultured bivalves (ranching)	NA	On bottom, under predator netting	**Moderate (Species specific)**	**Moderate (Species specific)**
General Conditions for Suspended bivalves	NA	Mussel lines, lantern nets etc.	**Moderate (Species specific)**	**Moderate (Species specific)**
Blue Mussel, ***Mytilus edulis***	Suspension	Bouchot poles	**High**	**Low**
	Suspension	Bottom culture	**Moderate**	**Moderate**
	Suspension	Suspended ropes	**Low/Moderate**	**Moderate**
Native Flat Oyster, ***Ostrea edulis***	Suspension	Intertidal Trestles/Baskets	**High**	**Low**
	Suspension	Bottom culture	**Moderate**	**Moderate**
	Suspension	Suspended nets/cages	**Moderate**	**Moderate**
Pacific Oyster, ***Crassostrea gigas***	Suspension	Intertidal Trestles/Baskets	**High**	**Low**
	Suspension	Bottom culture	**Moderate**	**Moderate**
	Suspension	Suspended nets/cages	**High**	**Low**
King Scallop, ***Pecten maximus***	Suspension	Bottom culture	**Low**	**Moderate**

Invertebrate Species	**Method of Feeding**	**Production Method**	**Technical Feasibility**	**Risk Levels - Environmental**
Baseline Lagoon Conditions	NA	NA	How likely is it that this species and technique could be successfully carried out based on available info?	Qualitative summary of likelihood of successful culture given combined constraints and environmental factors.
	Suspension	Suspended culture e.g. lantern nets	**Low**	**Moderate**
European Clam, ***Ruditapes decussatus***	Suspension/Deposit	Intertidal bottom culture	**High**	**Moderate**
Cockles, ***Cerastoderma edulis***	Suspension	Intertidal bottom culture	**Low (Currently)**	**High**
Macroalgae				
***Porphyra* spp.**	NA	Trestles/Nets/Ropes/Lagoon wall	**High**	**Moderate**
***Laminaria* spp.**	NA	Suspended systems/Lagoon wall	**High**	**Moderate**
***Ulva* spp.**	NA	Nets/Ropes/ Lagoon wall	**High**	**Moderate**

Figure 13: Summary of aquaculture option technical and environmental feasibility

SECTION 3 – AQUACULTURE SPECIES AND CULTIVATION OPTIONS FOR THE SUBTIDAL ZONE

3.1 Pacific Oyster (*Crassostrea gigas*) Cultivation

3.1.1 Overview and Background to Cultivation Activities in the UK

At present oyster fisheries and aquaculture in the UK are based around the native oyster (*Ostrea edulis*) and the Pacific oyster (*Crassostrea gigas* – see Figure 14) respectively. Today, stocks of the once abundant native species remain at very low levels due to over exploitation, the parasitic disease *Bonamia*, TBT pollution, mortalities due to previous severe winters and competition from exotic pests such as the slipper limpet. The decline of the native species led to the development of the culture of the Pacific oyster, an introduced species, which has proved to be an ideal candidate for aquaculture.

However, uncertainty currently exists in the UK over the potential effects of Pacific oyster farming on the wider marine environment due to the potential for wild settlement (Ref: Syvret *et al.*, 2008) which is in turn constraining existing and proposed Pacific oyster farm developments. Pacific oyster farming development, in southern areas particularly, is also severely hampered by a lack of suitable and available intertidal sites.

Figure 14: Intertidally grown Pacific oysters (Source: Aquafish Solutions Ltd.)

The Pacific oyster is a filter feeding bivalve mollusc that in the wild can be found on the lower shore and shallow sublittoral down to a depth of around 80 m (Source: http://www.marlin.ac.uk/species/detail/1676).

In terms of environmental conditions for aquaculture, seawater temperatures above 8 – 9 ^{o}C for much of the year are preferable for fastest growth, salinity should be generally above 20 PSU, a tidal flow of 1 – 2 knots (50 - 100 cm per second) is optimal as this will ensure a good supply of food, although less (around 0.5 knots) is acceptable (Source: Seafish Information Leaflet). In order to achieve good growth rates the Pacific oyster must be grown within the primary productivity zone (Ref: Syvret *et al.*, 2013).

3.1.2 Native/Non-Native Status

It should be noted that cultivation of the Pacific oyster has in recent years come under close scrutiny due to the perceived impacts of wild settlement of this non-native species through breeding of diploid oysters i.e. fertile and capable of reproducing. One potential mitigation approach to restricting wild settlement of Pacific oysters that has been proposed is the use of triploid seed which are considered to be broadly sterile and therefore unlikely to produce viable offspring in the wild, especially in the absence of other diploid oysters.

Previous discussions with NRW suggest that Pacific oysters may be grown in Wales by using triploid seed (Colin Charman, NRW, pers. comm. in Ref: Syvret and Woolmer, 2015). However, NRW have stipulated that at present Pacific oyster cultivation with triploid seed should only be considered in containment.

The relative reproductive potential of triploid seed is a complex subject and is discussed in detail in Syvret et al. (Ref: 2008) with an updated review of the subject in Syvret (Ref: 2015). Briefly, there are differences in the rates of triploidy levels achieved between the induction and the tetraploid production methods. Generally, the success rate of triploidy induction through chemical shock is only around 80 % i.e. 20 % may be fertile and theoretically able to reproduce. By comparison, the use of tetraploid male sperm to produce triploids is considered to be 100 % effective. However, at present there is no official supply of tetraploid male sperm available to UK hatcheries.

For subtidal cultivation, the practical implications are that triploid Pacific oysters can only be grown within baskets or cylinders suspended from long-lines rather than cultivated loose on the seabed. As such, whilst the technique of cultivation loose on the seabed is described within this report for both subtidal and intertidal cultivation as well as within the comparative assessment Matrix (see Section 2) in practise it is unlikely that permission would be obtained to carry out this cultivation technique.

We have been informed at the time of submission in early 2017 that Defra are currently developing a Pacific oyster policy which will examine to possibility of this species being naturalised.

3.1.3 Seed Availability

Seed or 'spat' oysters are available from hatcheries in a variety of size grades, usually from 4 mm to 30 mm shell length. The size grade quoted by suppliers generally refers to the size of mesh used to sort the oyster seed (3 mm to 14 mm mesh). Part-grown or 'half-ware' oysters may also be purchased from suppliers who specialise in this market. They are generally graded by weight and are usually sold at between 4 g to 15 g. Larger sizes can also be purchased.

As a general rule, whilst larger seed is more expensive to purchase it does have the advantage of lower mortality rates and less need for handling and grading. In terms of use offshore either in suspended culture or re-laid on the seabed, the higher energy environment would most likely mean that larger seed or even half-ware oysters would be required if significant mortalities are to be avoided (Ref: Syvret *et al*., 2013).

Cefas report (Ref: 2015) that in 2012, 423.5 million seed Pacific oysters were produced although there is no breakdown by size ranges given for this figure or eventual end destination for this seed. Of this 423.5 million seed the vast majority, 423.4 million, were produced in England with 0.1 million produced in Northern Ireland. As at 2012 there was no hatchery production of Pacific oyster seed reported in Scotland or Wales although some seed production has since taken place at the Ardtoe Marine Laboratory prior to its take-over by FAI Aqua Ardtoe. It is not known if further seed production will now be undertaken at Ardtoe. The Cefas production figures would not include seed production by Guernsey Sea Farms as this is based in the Channel Islands and therefore outside the UK (Ref: Syvret and Woolmer, 2015).

Discussions with NRW have indicated that only the use of triploid seed will be considered for cultivation within Welsh waters and these must be kept within containment (see Section 3.1.2).

3.1.4 Suitability for Cultivation within the Proposed Lagoon

We consider subtidal suspended Pacific oyster cultivation (long-line and within containment) to have a **High Technical Feasibility Potential** and a **Low Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 14.

We also consider that subtidal seabed Pacific oyster cultivation to have a **Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 13.

3.2 Native Oyster (*Ostrea edulis*) Cultivation

3.2.1 Overview

Currently there is little culture of native oysters (*O. edulis* – see Figure 15) practised in the UK due to the perceived difficulties in rearing this species when compared to the Pacific oyster. Supply for markets therefore relies predominantly on wild caught oysters which are dredged in areas such as South West England and in Essex.

The cultivation of native oysters that does take place mainly involves the re-laying in managed beds of either wild half-ware oysters or spat on cultch but there is now increasing demand for seed to be cultivated intertidally using modern oyster growing cylinders such as the ORTAC or Microreef systems (Tony Legg, Jersey Sea Farms, pers. comm.).

Figure 15: Wild caught native oyster (Source: Aquafish Solutions Ltd.)

In terms of environmental conditions for aquaculture, seawater temperatures above 8 to 9 ^{o}C for much of the year are preferable for fastest growth. Salinity of seawater should be above 25 PSU and ideally closer to full salinity i.e. above 30 PSU and up to 35 PSU. A tidal flow of 1 to 2 knots (50 to 100 cm per second) is optimal as this will ensure a good supply of food, although less (around 0.5 knots) is acceptable.

The longer the period of immersion the better the growth rate and some growers have commented that any exposure should be avoided as it may result in mortalities. Areas where the waters carry a very high silt burden should be avoided as this can cause smothering. In order to achieve good growth rates the native oyster must be grown within the primary productivity zone where phytoplankton levels are highest (Ref: Syvret and Woolmer, 2015).

3.2.2 Native/Non-Native Status

The decline in native oyster numbers led in the late 1990's to the development of a Biodiversity Action Plan (BAP) for this species, the Native Oyster Species Action Plan (NOSAP), for which the lead agency is currently the Shellfish Association of Great Britain. The main aim of NOSAP is to increase the abundance and geographical range of this threatened species where biologically feasible.

The sources of hatchery or extensively reared seed are limited to diploid oysters, i.e. fertile and capable of reproducing, and therefore any cultivation activities, within appropriate areas, that seek to increase potential broodstocks of this BAP species should be broadly welcomed in terms of their potential to help increase numbers of this now threatened species.

3.2.3 Seed Availability

Cefas report (Ref: 2015) that in 2012, 0.2 million seed native oysters were produced in Northern Ireland. As at 2012 therefore there was no hatchery production of native oyster seed reported in England, Scotland or Wales.

There is now however one commercial supplier of native oyster seed in England which is Seasalter (Walney) Ltd. There has also been some native oyster seed production at the Ardtoe Marine Laboratory prior to its take-over by FAI Aqua Ardtoe. However, it is not known if further seed production will now be undertaken at Ardtoe. Cefas do note (Ref: 2015) that in 2011, 200 tonnes of seed native oysters were collected from the wild although there are no equivalent capture figures for 2010 or 2012.

Extensive pond production of native oyster seed has been investigated in the past as a potential means of helping with restocking and regeneration of wild fisheries. In theory either the large or smaller-scale spatting pond approach, effectively managed, offers the opportunity to produce large numbers of low cost native oysters and so would seem to offer the type of seed volumes that might be needed for large-scale offshore culture (Ref: Syvret, 2015). The inclusion of spatting ponds for native oysters within the proposed lagoon in Swansea Bay could therefore provide a much-needed cost effective supply of biosecure native oyster seed for both aquaculture cultivation and more general restoration activities.

3.2.4 Suitability for Cultivation within the Proposed Lagoon

We consider subtidal suspended native oyster cultivation (long-line and within containment) to have a **Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 11.

We also consider that subtidal seabed native oyster cultivation to have a **Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 10.

3.3 Mussel (*Mytilus edulis*) Cultivation

3.3.1 Overview

The blue mussel (*Mytilus edulis* – see Figure 16) has been the subject of the most research in terms of its potential for culture in offshore waters. Mussel cultivation in the UK is the single largest and most valuable shellfish aquaculture activity.

Figure 16: The blue mussel (Mytilus edulis) Images: Left = Seabed cultivated mussel after cleaning; Right = Rope-grown mussels after harvesting (Source: Seafish Hyperbook and Aquafish Solutions Ltd.)

The blue mussel is a filter feeding bivalve mollusc that is very common all around the coast of the British Isles, with large commercial beds in the Wash, Morecambe Bay, Conway Bay and the estuaries of South West England, North Wales, and Western Scotland. Mussels occur from the high intertidal to the shallow subtidal attached by fibrous byssus threads to suitable substrata (Source: http://www.marlin.ac.uk/species/detail/1421).

Mussels can tolerate a wide variety of environmental conditions and so are found from brackish estuarine waters through to fully marine conditions. In terms of UK cultivation, mussels start to grow in the spring when seawater temperatures reach 8 to 9 °C. Growth rate reaches a maximum in July or August when water temperature peaks (usually 16 to 18 °C) and then falls off again as the temperature drops back below 8 to 9 °C in November or December.

Salinity should be above 20 PSU and for seabed cultivation tidal flows of 1 to 2 knots (50 to 100 cm per second) are optimal (Source: Seafish Information Leaflets). In order to achieve good growth rates mussels must be grown within the primary productivity zone (Ref: Syvret *et al.*, 2013).

3.3.2 Native/Non-Native Status

The blue mussel is a native species to the British Isles and so there are no non-native issues in this respect. Other mussel species can also be found around the British Isles. These include *Mytilus galloprovincialis* (the Mediterranean mussel), which is found around the South West of England where it may hybridise with *M. edulis*, and *Mytilus trossulus*, which is considered a pest species to aquaculturists due to its weak shell and poor meat yields (Ref: Syvret *et al*., 2013)

3.3.3 Seed Availability

At present in the UK mussel cultivation is reliant on natural spat-falls of mussel seed although there is currently research being carried out at the NAFC Marine Centre in Scotland to ascertain if this species can be practically and economically reared in a hatchery (see: http://europeanmarinesciencepark.co.uk/news-events/2016/mussel-spawning-trials-underway-at-new-17m-pilot-hatchery-in-shetland/). For seabed culture, wild spat-fall can often take the form of ephemeral seed beds that, if not collected, tend to be disbursed by storms, smothered by sediments or predated by starfish. This is the main source of seed collected by the North Wales seabed mussel cultivators. Rope-culture of mussels relies on spat-fall on to dropper or collector ropes that are suspended from the long-lines (see Figure 17).

Figure 17: Collection of seabed mussel using a light dredge and mussel spat on a collector rope. (Source: Deepdock Ltd. and Seafish Hyperbook)

Collection of seed through dredging or the use of collector ropes cannot of course be guaranteed, although in terms of Swansea Bay, there is fairly regular mussel settlement in the outer bay and along the Gower coast. Whiteford Point in particular has ~1000 tonnes of mussel available every year.

3.3.4 Suitability for Cultivation within the Proposed Lagoon

We consider subtidal suspended native mussel cultivation (long-line with rope droppers) to have a **Low/Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 8.

We also consider that subtidal seabed native mussel cultivation to have a **Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 7.

3.4 King Scallop (*Pecten maximus*) Cultivation

3.4.1 Overview

The king scallop (*Pecten maximus* - see Figure 18) is the single most important bivalve mollusc in UK fisheries in terms of volume and value. The MMO report (Ref: Marine Management Organisation, 2016) that scallop landings into the UK from wild fisheries ranged from 54 to 41 thousand tonnes between 2011 and 2015. Typical prices for these scallops during this period was around £1.50 per kilo meaning that the value of landings is in excess of £60 million per annum.

Unlike mussels, where aquaculture plays a major role in production, the vast majority of the king scallop product available to the market comes from the wild fishery. For a general review of king scallop fisheries see the following web-link for the FAO factsheet;

http://www.fao.org/fishery/species/3516/en

Figure 18: King scallops on the seabed (Source: Craig Burton)

The king scallop has been recorded around most coasts of Britain and Ireland but with only scattered records from the east coast of Great Britain. These scallops are usually found in a shallow depression in the seabed. King scallops prefer areas of clean firm sand, fine or sandy gravel and may occasionally be found on muddy sand. Distribution in this species is invariably patchy (Source: http://www.marlin.ac.uk/species/detail/1398). Hard sediments are generally unsuitable as the scallops are unable to bury themselves sufficiently to avoid predation. Scallops are a fully subtidal species and so require continuous immersion in seawater. The king scallop can naturally be found down to depths of up to 100 m+, but in terms of aquaculture, sites with a depth of water between 15 to 30 m are considered optimal (Source: Seafish Hyperbook).

In terms of environmental conditions for aquaculture, seawater temperatures should be at least 10 ^{o}C and the best sites for scallop cultivation are those where temperatures are between 10 ^{o}C and 17 ^{o}C for the maximum length of time. Summer temperatures >18 - 20 ^{o}C and winter temperatures <4 ^{o}C can be stressful to scallops. Salinity should be generally above 30 PSU. A tidal flow of 0.4 to 1.8 knots (0.2 to 0.9 metres per second) is suitable for suspended culture systems (Ref: Laing, 2002), whilst 1 knot is optimal for seabed culture although up to 2 knots can be tolerated (Ref: Seafish Information Leaflet). In order to achieve good growth rates the king scallop must be grown within the primary productivity zone (Ref: Syvret *et al.*, 2013).

3.4.2 Native/Non-Native Status

The king scallop is a native species to the British Isles and so there are no non-native issues in this respect.

3.4.3 Seed Availability

King scallops are notoriously hard to produce on a commercial-scale in a hatchery environment. Laval cultures becoming infested with *Vibrio* sp. bacteria are one of the commonest causes of batch failures within hatchery culture (Ref: Syvret, 1997). Whilst a scallop hatchery does exist in the Bay of Brest, current concerns over biosecurity would prevent any introductions from this area. The Norwegian hatchery, Scalpro, has in the past provided some seed for scallop cultivation in the UK. Cultivation of scallops can also be based on the collection of wild caught seed.

Collection of wild seed is generally carried out by deploying collector bags (see Figure 19) in areas known to have a track record for seed settlement. Long-lines and collectors (e.g. an onion bag containing a filler material) are put out in the sea in May through to July at a time to coincide with the peak period of spat settlement (Ref: Syvret *et al.*, 2013).

Figure 19: Scallop spat collector bags ready to be dispatched (Source: Seafish Hyperbook)

It is possible to obtain between 50 – 100 king scallop spat per collector at an average site. When available, seed (10 to 25 mm) can also be purchased from commercial collectors. The larger the seed the more expensive it is, but survival rates will be better (Source: Seafish Hyperbook).

It is however important to note that whilst this method of collection of spat can be successful, settlement is often very variable between sites and between years. Whilst this type of seed collection has been able to support a small cultivation industry for this species, this degree of variability in settlement rates from year to year means that security of seed supply is likely to continue to be an issue for commercial culture. It would seem therefore that until reliable and successful hatchery techniques are developed, that large-scale offshore cultivation of the king scallop cannot be considered a realistic possibility (Ref: Syvret *et al.*, 2013).

3.4.4 Suitability for Cultivation within the Proposed Lagoon

We consider subtidal seabed scallop cultivation to have a **Low Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 15.

We also consider subtidal suspended scallop cultivation to have a **Low Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 16.

3.5 Suspended Shellfish Cultivation Techniques

Whilst subtidal aquaculture production levels of oysters, either suspended or on the seabed, are limited in the UK at present, both the Pacific and native oyster are considered to be good candidates in this respect. The generally high market value of king scallops also makes it a good candidate for increased production through aquaculture although seed supply remains an issue.

Previous trials have shown that both oyster species and scallops can grow and survive well both in the nearshore and higher energy offshore environments. Subtidal cultivation techniques are broadly similar for both types of shellfish. Subtidal mussel cultivation by comparison is widely practised in the UK with significant rope-grown mussel production in Scotland. More recently, offshore rope-mussel farms have been established off the south coast of England.

One important distinction between fixed gear and seabed cultivation concerns the rights of ownership of the shellfish. With fixed gear cultivation, normally through a Crown Estates lease, the containment of the shellfish brings with it rights of ownership where unauthorised removal constitutes theft. TLSB are currently discussing with The Crown Estate the marine licensing position within the proposed Swansea lagoon in terms of the ability to allow secondary co-location activities such as mariculture. With seabed cultivation, a right of ownership, normally through a Several Order, must be obtained that removes the public right to fish. At present, it is unknown whether the area within the lagoon will still have a public right of fishery. It would of course seem unlikely that TLSB would welcome uncontrolled commercial activities within the lagoon.

Sections 3.5 and 3.6 provide a general overview of subtidal shellfish cultivation and harvest techniques and equipment.

3.5.1 Site Selection and Location of Fixed Gear Cultivation

Site selection will be based on a number of factors including water temperature (max/min and average), water quality, phytoplankton levels, seed availability, substrate type, water depth, current velocity, other marine uses etc. as well as logistical considerations such as distance from shore.

There have already been some moves ‘offshore’ in terms of UK shellfish cultivation, most notably through long-line rope mussel production. Up until recently in the South West of England these rope mussel farms have been limited to nearshore sites where they still receive a degree of protection from the prevailing weather conditions. However, trials are currently underway off the south coast of England to test the performance of true offshore farms operating in exposed conditions (Ref: Syvret *et al*., 2013). The initial results from these trials have proved successful both in terms of the performance of the equipment and growth and mortality rates of the mussels. Environmental impacts have also been shown to be low.

3.5.2 Design Considerations for Suspended Shellfish Cultivation

The majority of development work to date in terms of offshore suspended shellfish cultivation has been on mussels as they show rapid growth to market size and attach naturally to substrates through means of byssus production. The ability to self-attach to a cultivation substrate means that they do not require the use of containment structures in the same way as other shellfish such as oysters (Ref: Syvret *et al*., 2013). Figure 20 shows some of the system designs that have been considered for offshore cultivation in association with wind farms.

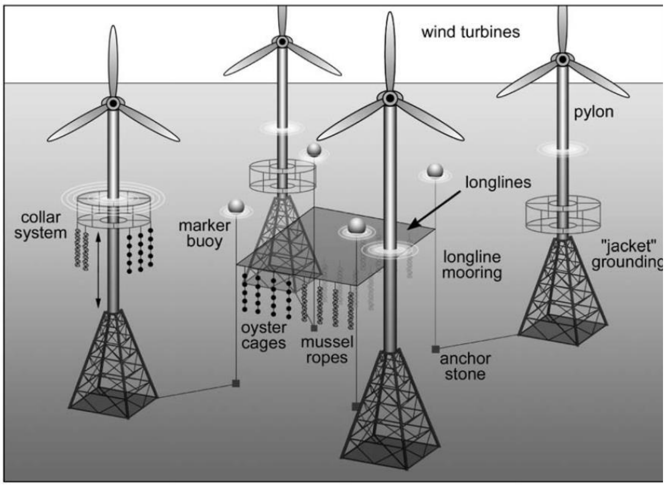

Figure 20: Diagrammatic representation of possible offshore shellfish aquaculture installations Left-hand image: Installations between existing wind turbines; Right-hand image: Multi-use of wind turbine structures for co-location with shellfish aquaculture (Source: Buck et al., Ref: 2004)

Figure 21 shows the offshore mussel system that was designed by Offshore Shellfish Ltd. (OSL) for their mussel farm off the south Devon coast. This farm isn't reliant on sheltered headlands for protection and operates in true offshore conditions.

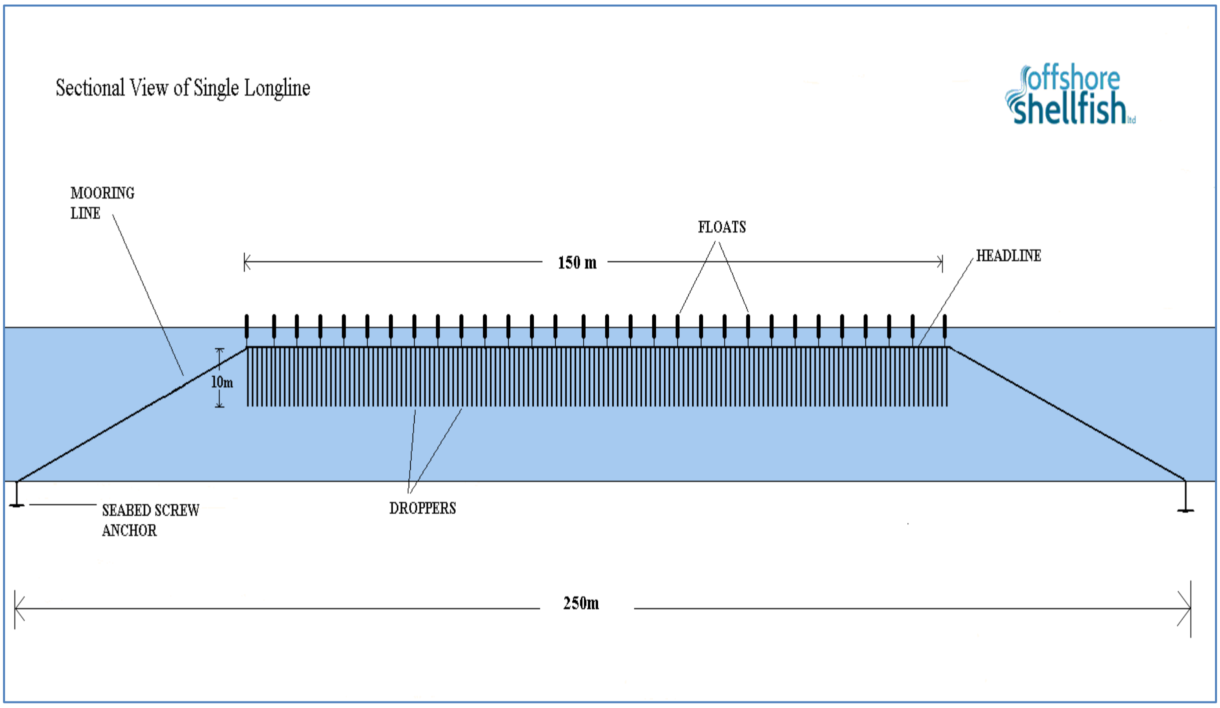

Figure 21: Individual offshore long-line system (Source: Offshore Shellfish Ltd.)

The main headline shown in Figure 21 is 150 m long and the whole long-line will be secured with seabed screw anchors over a total length of 250 m. This is generally in keeping with the main design parameters of other offshore mussel farms.

The advantage of the submerged system is that the shellfish are located away from the most extreme impacts of wave action which occur at the sea surface. Therefore, by placing the shellfish below the surface the chance of losses through wave action are reduced.

The use of pencil floats (see Figures 21 and 25) at the surface as opposed to circular buoys is recommended as their profile creates less resistance to vertical water movement. This means that pencil floats help to reduce the rise and fall of the long-line with sea swell. Reduced motion of the long-line is preferable as this will decrease stress levels on the shellfish and therefore promote faster growth. OSL has pioneered the use of pencil shaped floats to reduce vertical motion of the headlines in swell. As with seabed cultivation, the shellfish must not be placed so deep that there is insufficient food to allow reasonable growth rates (Ref: Syvret *et al*., 2013).

Screw anchors, which are shown in Figure 22, are a highly effective means of securing fixed gear in higher energy environments and are being used in the offshore mussel farm that is operated by OSL off the south Devon coast.

OSL have pioneered the use of this technique in UK aquaculture and have recently built and equipped a vessel specifically designed to install these anchor systems (see Figure 22).

Figure 22: Screw anchor installation vessel and example of a screw anchor (Source: Offshore Shellfish Ltd. http://www.offshoreshellfish.com/)

3.5.3 Suspended Cultivation Techniques for Oysters

There are several purpose designed shellfish cultivation systems currently being produced worldwide that would be suitable for fixed gear or suspended cultivation of oysters. An example of the Australian AquaTray system produced by TTP Plastics (Tooltech) is shown in the Figure 23. With this system, the trays can be separated by risers (as shown) or placed flat together where smaller oysters are being on-grown or where sea conditions are rougher and the systems may be subject to more movement.

Figure 23: AquaTray system being used in offshore suspended culture of Pacific oysters. Top left image: Purpose built aquaculture vessel for use with AquaTray system. Top right image: AquaTrays being deployed offshore (marker buoy in background) Bottom image: AquaTrays after recovery from subtidal culture (Source: Peter Hoare)

A Californian five-tiered lantern net system currently being used by the Santa Barbara Mariculture Co. to farm Pacific oysters is shown in Figure 24. This farm is 28 hectares (70 acres) in size and located about 1.2 km (0.75 miles) off the Santa Barbara coast.

The farm uses twelve 137 m long-lines submerged to a depth of 6 m and running parallel to the shore in between 24 to 27 m depth of water. The area receives 0.5 to 1 metres per second wind chop on a regular basis and 3m swell occasionally.

Extreme sea conditions are rare but may reach 6 m swells and 60 knot winds. The farm is serviced where possible on 2 to 4 days every week, year-round. Testing is carried out each week for algal toxins (PSP and ASP) and the water is also tested for faecal coliform levels on a monthly basis and after heavy rainfall events.

Survival of the hatchery reared oyster seed is reported to be excellent under these offshore conditions.

Figure 24: Five-tiered lantern net used for open water oyster culture. Note: The main long-line is shown with the hydraulically driven retrieval block. (Source: Cheney et al., 2010)

The 137 m long-lines are constructed of 25 mm diameter rope with no metal connections. The long-lines are kept in place using concrete anchors designed to grip the ocean floor. Long-lines are reported to have an operational life of up to 7 years. Each long-line can hold up to 6.8 tonnes of shellfish. As shellfish grow then more floats are added to maintain the 6 m depth.

At harvest a mechanical line hauler retrieves the head-line and the lantern nets containing the Pacific oysters are swung on-board. The lantern net system doesn't however lend itself to mechanical handling and so servicing of these systems (e.g. cleaning of biofouling) is a labour-intensive process. Productivity and condition indices are both reported as being high with Pacific oysters grown from 6 mm seed to a market size of 100 mm in 10 months (Ref: Syvret *et al.*, 2013).

3.5.4 Suspended Cultivation Techniques for Mussels

Suspended mussel culture generally takes place in relatively sheltered estuarine or marine environments either using long-lines or mussel rafts although there are now moves towards farming mussels offshore (see Figure 25). Typically, a long-line in the UK would consist of either a single or double headline supported by plastic floats at regular intervals.

The line is anchored to the seabed or shore at either end. The type and size of the anchor system will be matched to the local conditions. Long-line length is generally around 200 to 400 m with the floatation buoys spaced around 3 m apart, but this is dependent on load at the time. The diameter of the headline is normally between 20 to 32 mm (Source: Seafish Hyperbook).

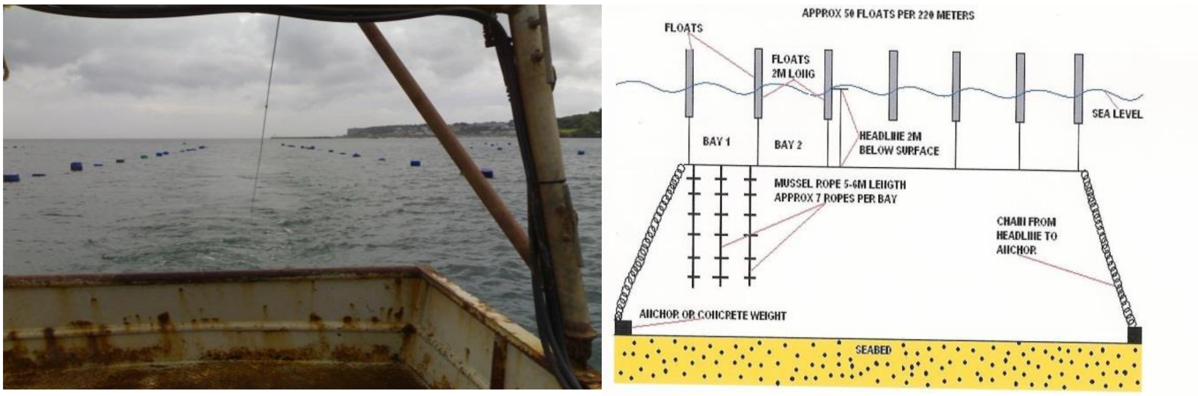

Figure 25: Images from current SW England-based nearshore rope-mussel cultivation operations. Left-hand image = View across Torbay from harvesting vessel; Right-hand image = generalised long-line system design used in the SW (Source: Aquafish Solutions Ltd.)

Mussels may be grown on individual droppers of between 5 to 10 m in length, depending on prevailing minimum water depth, or on a continuous line looped below the headline. The continuous loop system generally has the advantage of allowing increased mechanisation of servicing and harvesting. Space between long-lines may vary between sites but will be matched to the size of the aquaculture vessel servicing the lines (see Figure 26).

Figure 26: Individual rope mussel dropper and continuous mussel loop

Left-hand image = Individual dropper being raised on an estuary based rope mussel farm (Source: Aquafish Solutions Ltd.); Right-hand image = Seeded mussel ropes being attached in a continuous loop to the main long-line in an offshore farm (Source: Cheney at al., 2010)

There has been some cultivation using rafts in the UK which are typically 10 m^2, consisting of two floatation pontoons or float arrays, overlaid with a wooden framework, with supports approximately 0.5 m apart. Rafts may be anchored individually or form part of a larger flotilla. The mussels are collected and grown on ~12 mm diameter rope droppers that are often between 5 to 10 m in length, depending on the prevailing minimum depth of water (Source: Seafish Hyperbook in Ref: Syvret *et al*., 2013).

3.5.5 Suspended Cultivation Techniques for Scallops

The limited current level of cultivation of king scallops in the UK is carried out either through suspended culture or subtidal culture on the seabed. The Seafish Hyperbook contains a good schematic that summarises both these cultivation techniques (see Figure 27).

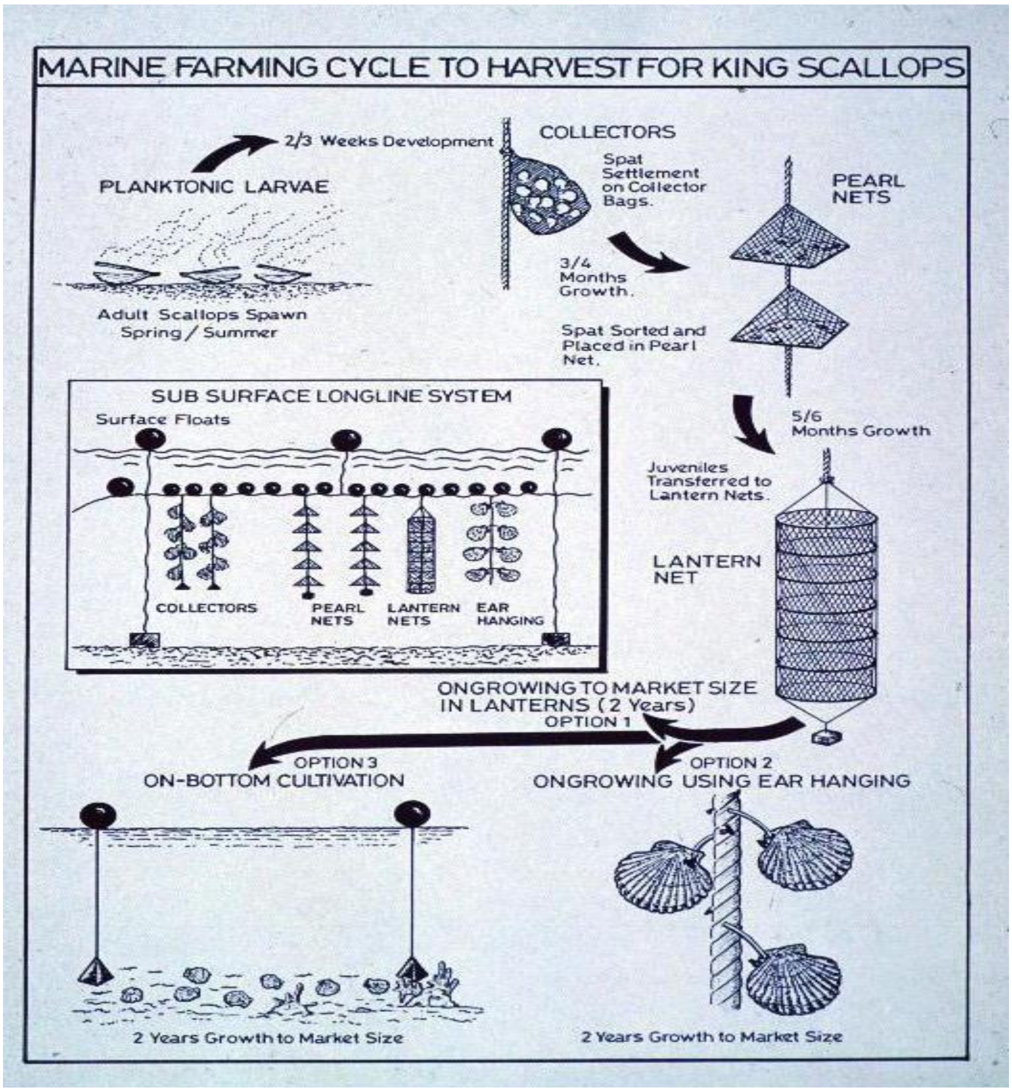

Figure 27: Schematic of current scallop cultivation techniques

(Source: Taken from the Seafish Hyperbook, original source unknown)

To summarise the schematic shown in Figure 27, scallop spat (at 10 to 15mm) can be taken off the collectors in October/November (i.e. 3 to 4 months after the peak spawning period) and transferred into pearl nets with ~10 nets per dropper. Based on no more than 33 % flat surface coverage, stocking densities normally average about 80 to 100 small (10 to 20 mm) seed and 20 to 30 larger (20 to 30 mm) juveniles per pearl net. Another option is to transfer spat from the collectors to North-West Plastic (NWP) trays placed in stacks on the seabed or suspended from long-lines (at least 3 m below the surface of the water). At approximately 1 year old (~25 mm), scallops can be transferred into lantern nets at 50 to 60 seed per layer for the next stage of on-growing. These will need to be thinned to 30 per layer as they grow. Numerous studies (reviewed in Ref: Guillermo, 2007) have shown that the stocking density and growth are directly related, with higher stocking densities leading to reduced growth rates per scallop.

King scallops can continue in lantern nets until they reach market size (initial stocking densities for 60 to 80 mm scallops is 10 to 15 per layer) or they can be transferred to the seabed as they are now less prone to losses from predation. Whilst on-growing to market size within containment offers more protection of the stock it does come at a high cost in terms of the time taken to keep the nets or containers clean.

An alternative suspended culture technique is called ear-hanging where a hole is drilled in the shell and the scallop is tied to the long-line. Trials would be required to investigate whether ear hung scallops would remain attached to the dropper in higher energy environments. Cultivation in weighted cages on the seabed is also a possible option in more nearshore areas or can be used as a nursery system before placing part grown scallops on the seabed.

The type of suspended cultivation techniques described for Pacific and native oysters in Section 3.5.3 should work with king scallops provided that the scallops can be permanently retained within the containment structure. One potential drawback with suspended culture in an offshore environment may be that scallops subject to movement by wave action will experience increased stress levels (Ref: Laing, 2002) which may result in decreased growth rates.

3.6 Seabed Shellfish Cultivation Techniques

3.6.1 Seabed Shellfish Cultivation Considerations

The cultivation of shellfish on the seabed has the advantage over fixed gear cultivation techniques in that there is no equipment to deploy, maintenance of the stock is minimal and there is no need to clean cages or grade shellfish. In economic terms therefore, the major cost is that of the harvesting system, whether by vessel or diver, but great savings are made in terms of time and labour inputs during the grow-out phase of cultivation.

The depth of water in which seabed cultivation of shellfish can take place will be primarily governed by the availability of their phytoplankton food source. If the shellfish are placed too deep, where primary productivity levels are reduced due to lower light penetration or reduced mixing, then a consequent reduction in growth levels will occur.

In higher energy offshore environments, shellfish would need to be placed at a sufficient depth to avoid the impacts of waves which may cause movement of the shellfish, or alternatively smothering, should sediments be mobile under these conditions. It can be seen therefore that there is a balance to be struck between the need to supply the shellfish with sufficient food to promote growth whilst ensuring that they are sheltered from excessive environmental disturbance (Ref: Syvret *et al*., 2013).

3.6.2 Subtidal Harvest of Seabed Cultivated Shellfish Using Eco-harvesters

For relatively shallow and sheltered waters it may be possible to use an 'eco-harvester' which is an aquaculture barge fitted with a 'pump-scoop' harvesting system and elevator (see Figure 28). This system is effective for a range of shellfish species including oysters, mussels and clams.

Figure 28: Eco-harvester operating on a south coast site. Left-hand image: Pacific oyster seed being spread over an on-growing site; Right-hand image: Harvesting of oysters using an elevator dredge. (Source: Aquafish Solutions Ltd.)

Whilst this system is very effective in shallow waters with a relatively clean flat substrate it is not designed for operations in deeper water where more traditional dredge designs would be required (Ref: Syvret *et al*., 2013).

3.6.3 Subtidal Harvest of Shellfish Using Dredges

Hand-hauled Dredges: Light weight hand-hauled dredges, such as those still employed in the Fal native oyster fishery (see Figure 29) of Cornwall, were used in South Wales for at least 500 hundred years until the early 20th Century when the advent of powered vessels enabled the use of larger dredges.

Figure 29: Traditional hand-hauled native oyster dredge from the River Fal. (Source: Salacia-Marine)

Hand-hauled dredges are generally deployed from small open fishing vessels <8 m in length by a variety of methods including anchor dredging, sail dredging and powered tows (Ref: Syvret and Woolmer, 2015).

Heavy Dredges: Heavy dredges employed by larger fishing vessels are of a similar design to hand-hauled dredges but scaled up accordingly (see Figure 30). The basic design remains the same with an A-frame forming the basis of the dredge with a belly of steel rings, however the upper net bag is often replaced with a continuation of the belly rings.

The other main differences are the addition of strengthening bars to the A-frame and often a rectangular or curved frame to the mouth of the bag to keep it open. This type of dredge is usually deployed either singly or in pairs from fishing vessels equipped with a hydraulic trawl winch and aft A-frame for lifting onto the deck.

Figure 30: Heavy dredges used in shellfish harvesting. Left-hand image: Oyster dredges Right-hand image: Mussel dredge used in the Menai Straits (Sources: Sussex SFC and Deepdock Ltd.).

Oyster Tongs: A common oyster fishing method employed in the eastern USA, but not currently used in UK fisheries, is the use of oyster tongs (see Figure 31). These tongs are a form of long-handled basket normally deployed in shallow waters where they manually remove oysters from the seabed using a scissor-like action.

Vessel sizes employing the use of tongs generally range from small skiffs up to 10 m+ vessels. In deeper water a modified version colloquially named Patent Tongs are used. These Patent Tongs have been shown to be very efficient at harvesting oysters when compared to dredges.

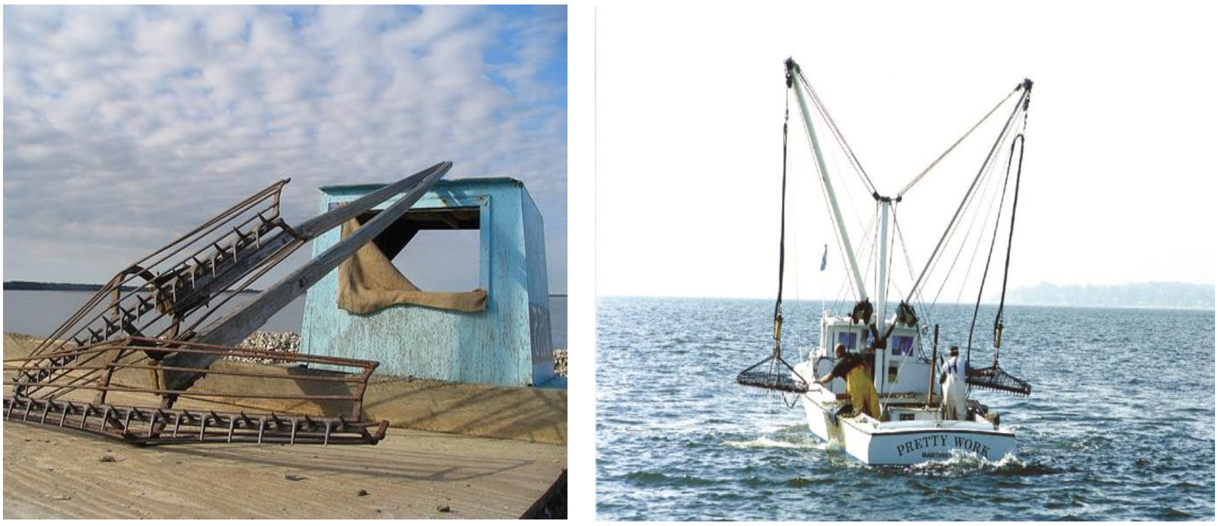

Figure 31: Oyster tongs

Left-hand image: Typical oyster tongs used in Crassostrea virginica fisheries in the USA. Right-hand image: Patent tongs being recovered (Source: Maryland Watermen's Association)

In general, these oyster tongs are used on flat substrates, free of rocks or stones, where there is a relatively high stocking density. These conditions may well mirror suitable benthic subtidal areas for oyster cultivation in the UK and as such may be worth consideration in future trials in the proposed lagoon although it is difficult to see if there would be any advantage over a dredge (Ref: Syvret and Woolmer, 2015).

3.6.4 Seabed Cultivation Techniques for Scallops

Continuing on from Section 3.5.5, in terms of seabed cultivation, king scallops are transferred to the seabed at 2 years old (50 mm shell height). Seeding densities for seabed cultivation are normally 5 or 6 animals per m^2 but can be up to 24 per m^2 in high productivity areas. As scallops are mobile, they can move from seeded plots if conditions are not suitable or there are strong currents. Trials have been carried out using 'cage' type systems to try and retain seabed cultivated scallops within a set area.

Avoidance or removal of predators at seeding and then during cultivation is considered to be essential and may well be carried out by divers. Stacks of NWP trays and heavy cages have also been used. There is limited information on the criteria for these methods and their advantages/disadvantages compared with other techniques. As a general guide, a high current speed (> 2 knots) is needed to ensure scallops in the centre of cages get an adequate food supply. A firm substrate is essential to prevent the structure sinking into the substrate and depths of 5 to 20 m are likely to be the mostsuitable for this type of culture (Source: Seafish Hyperbook).

SECTION 4 – AQUACULTURE SPECIES AND CULTIVATION OPTIONS FOR THE INTERTIDAL ZONE

4.1 Introduction

Sections 4.2 to 4.6 present a summary of possible shellfish species and cultivation techniques that could be considered for the intertidal zone of the proposed lagoon in Swansea Bay. The species' biology, environmental requirements harvesting techniques and equipment requirements are also discussed.

4.2 Native Clam (*Ruditapes decussatus*)

Section 4.2 gives a general overview of clam culture (see Figure 32) covering the techniques and conditions required to cultivate the native clam (*Ruditapes decussatus*).

Figure 32: Cultivated clams. (Source: Aquafish Solutions Ltd.)

4.2.1 Biology & Environmental Requirements

- In the UK, clams start to grow in the spring when seawater temperatures reach 8 - 9 °C. Growth rate reaches a maximum in July or August when water temperature peaks (usually 12 - 20 °C) and then falls off again as the temperature drops back below 8 - 9 °C in November or December.
- Salinity should generally be above 20 PSU and intertidal and shallow sub-littoral locations are best. Clams will grow more slowly higher up the shore due to the length of periods when they are exposed to air and cannot feed.
- Clams live buried in the substrate. Their survival is better in sand or gravel substrates but it is also possible to grow them in muddy areas.
- Tidal flow of 1 – 2 knots (50 - 100 cm per second) is optimal as this will ensure a good supply of food, although less (around 0.5 knots) is acceptable.

4.2.2 Cultivation Techniques

- Manual methods can be used for small-scale cultivation. More mechanisation is needed for laying mesh and harvesting as scale of production is increased.
- Seed are available from commercial hatcheries at a range of sizes from 4 to 30 mm shell length. Larger seed (10 mm+) is more expensive but has higher survival rates. Alternatively, small seed can be purchased and held in nursery trays on trestles on the foreshore until large enough to sow**.**
- Manila clam seed can survive winter temperatures at/below 3 °C for short periods whereas native clams lose condition at around 6 °C.

- Manila clams generally have higher survival rates than native clams with around 50 % of seed reaching market size. Native clam survival is more likely to be around 30 %.
- Clams are usually grown in plots under lengths of netting (25 m x 2 m, with 5 x 5 mm mesh size) to protect them from predators, and in the case of non-native species, to also keep them in containment (see Figure 33). Sowing densities should be in the order of 400 to 800 per m^2. Clams can be spread without netting but this will result in higher mortality rates due to predation. Predators include birds such as oyster catchers and curlews, crabs and starfish.
- The edges of the netting are buried in the substrate down to 10 cm and kept in place with rope stapled round the edges and metal hooks every 0.5 m pushed through the mesh into the substrate.
- Since the clams will take around 3 years to grow to a harvest size, it will be necessary to change the netting at least once during this time, increasing the mesh size to allow greater water flow.

Figure 33: Clam cultivation under predator netting (Sowing seed clams prior to covering with netting; Source: Seafish)

- Clams can also be grown in oyster bags sunk into the sand in rectangular plots (0.8 x 0.5 m) and staked into place leaving about 2.5 cm protruding above the sand. Initial stocking density should be approximately 400 to 500 seed per m^2 @ 8 mm shell length.
- Clams can be grown in trays or bags on trestles although this is a less common method. Clams grown in this way are exposed to environmental extremes and tend to have misshapen shells due to the coarse substrate that must be added to the trays or bags.
- When deciding upon a culture method the relative costs of production must be carefully considered as bag and tray culture can be up to four times more expensive than sowing seed into meshed plots.

4.2.3 Harvesting

- In southern parts of the UK, Manila clams generally reach market size (around 40 mm shell length) in 2 - 3 years; native clams and American hard shell clams take 3 - 4 years.
- The normal harvesting season is from late August/September through to April.
- Clams harvested at around 20 g live weight usually have a meat yield representing from 20 % to 30 % of their total weight depending on the productivity of the bed and the time of year.
- Low-shore or sub-littoral plots can be harvested by hydraulic dredging using water jets to fluidise the sediment (see Figure 34). Newer more environmentally friendly dredges are now available. These minimise the disturbance to the seabed and return undersize clams to the substrate.

Figure 34: Elevator dredge shown harvesting clams (Source: Seafish)

- Harvesting of clams grown in the ground in intertidal locations can be carried out by hand raking or by mechanised methods including the use of potato or carrot harvesters towed by tractors (see Figure 35).
- After harvesting, the clams will require washing, grading and bagging before being sent for depuration.

Figure 35: Mechanised methods of clam harvesting Left-hand image: Harvesting Japanese carpet shell using a tractor equipped with a blade and conveyor belt (hard bottom). Right-hand image: Harvesting Japanese carpet shell using a small tractor in small plots and soft bottom (Source: FAO)

4.2.4 Equipment

- At increased production levels mechanisation will be needed in order to lay mesh and to harvest the clams. Equipment that may be needed includes tractors and trailers, small boats, quad bikes.
- Additional equipment may include storage and dispatch facilities, a depuration facility, weighing and grading machine, packing system, stock handling system.
- A clam farmer will also need an assortment of smaller pieces of equipment and safety clothing in addition to the more specialised items. Examples of the equipment required include First Aid kit, lifejackets/buoyancy aids, especially when working from small boats, signal flares for boat work, pressure washer, gloves, knives, communication equipment (mobile phone or VHF radio).

4.2.5 Suitability for Cultivation within the Proposed Lagoon

With any new site and with any shellfish species, it would be recommended that pilot-scale trials are carried out initially to obtain an assessment of shellfish growth and mortality rates, equipment performance, impacts on other marine users, changes to the substrate and immediate areas as well as any other environmental/ecological impacts and benefits. A minimum of 12 months would be required in order to assess the performance and impacts of the culture systems i.e. across all seasons. Once the initial pilot-scale trials have been completed and performance assessed, then further commercial-scale trials can then be carried out to assess full economic viability of the species and systems being considered. In terms of any impacts on other users or on the marine environment, an adaptive management plan incorporating mitigation measures can be agreed and implemented.

Once a successful commercial cultivation operation has been established then there will be scope to test new systems and species starting again at a pilot-scale level.

We consider intertidal seabed native clam cultivation (under mesh) to have a **High Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 17.

4.3 Pacific Oysters (*Crassostrea gigas*)

Section 4.3 provides a general overview of intertidal triploid Pacific oyster cultivation (see Figure 36). Limitations on the types of culture techniques that could be considered at present in Welsh waters are discussed in Section 3.1.2.

Figure 36: Intertidally grown Pacific oysters **(Source: Aquafish Solutions Ltd.)**

4.3.1 Biology & Environmental Requirements

- Seawater temperatures above 8 – 9 °C for much of the year are preferable for fastest growth
- Salinity generally above 20 PSU in an intertidal area sheltered from extreme wave action or strong tidal flows.
- For preference, the seabed should be clean and firm in order to avoid siltation and support the trestles. Areas where the waters carry a very high silt load should be avoided as this can cause smothering.
- A tidal flow of 1 –2 knots (50 - 100 cm per second) is optimal as this will ensure a good supply of food, although less (around 0.5 knots) is acceptable.
- The trestles should be arranged to maximise seawater flow through the site. If this is not achieved it can result in decreased food availability to the oysters and increased sedimentation around the trestles.
- Maximum of 4 hours aerial exposure per tidal cycle for good growth, less is preferable. The longer the period of immersion the better the growth rate, although some exposure is required to promote shell hardness.
- During winter months, exposure to very cold winds and air temperatures close to or below freezing can cause the oysters to die. Similarly, air exposure during hot summer days should also be avoided.
- Areas with poor water exchange should be avoided as this may result in oxygen depletion, particularly during warm weather. This can weaken or kill the stock.

4.3.2 Cultivation Techniques

- Pacific oysters are usually grown in plastic mesh bags secured to metal trestles in the intertidal zone. Wire-mesh 'trays' are also available. Figure 37 shows a comparison between the traditional French-style *poche* bags with rigid steel trestles and the ORTAC rigid cylinder and a one-piece steel staple.

Figure 37: Cultivation on trestles – French Poche system (top) vs. ORTAC staple (lower) **(Source: Aquafish Solutions Ltd.)**

- Other alternatives to the French *poche* bag system include the rigid cylinder containers produced by the Australian companies Aquapurse, SEAPA and BST-Boddingtons some of which are shown in Figure 38. Depending on the prevailing environmental conditions these systems can be mounted on high-tension long-lines or on steel or wooden trestles.

Figure 38: Intertidal fixed long-line cultivation of oysters. **Left-hand image; = BST system mounted on high tensile steel wires between posts. Right-hand image; Aquapurse system mounted on a wooden frame. (Source: Aquafish Solutions Ltd.)**

- Alternatively, in some areas, Pacific oysters may be laid directly on to the seabed or on to 'mats' laid on very soft substrates (see Figure 39). The seabed plots are often known as 'parcs'.

Figure 39: Pacific oyster cultivation in managed parcs **(Source: Aquafish Solutions Ltd.)**

- Pacific oysters can also be 'ranched' i.e. scattered on sea bed without predator protection. This technique is carried out successfully on one existing sub-littoral south coast site and there it has the advantage of allowing the increased use of mechanisation through the use of an aquaculture barge or 'eco-harvester' with an elevator dredge fitted with fluidising head.
- Discussions with NRW have however indicated that at present Pacific oyster cultivation even with triploid seed will only be considered within containment e.g. bags or cylinders.
- A French style 'chaland' aquaculture barge (see Figure 40) may be the most appropriate form of access for sites where impact on designated features/species, e.g. over wintering birds in the intertidal zone) needs to be avoided.

Figure 40: French chaland aquaculture barges

(Source: Navalu Aluminium Boats)

- There is a price premium that can be obtained in the French market for what are termed *fines de Claire*. These highly prized Pacific oysters are 'finished' for between one to two months at low densities in specially converted salt marshes or *claires*. Here the nutrient rich water often gives rise to blooms of *Navicula* spp. phytoplankton which causes the oysters to take on a much-prized green colouration around the gills. Figure 41 shows a website advert for Spanish customers of a *fine de claire* oyster with the Label Rouge certification.

***Figure 41: Label Rouge fine de claire oyster* (Source: http://www.ostrasorlut.com/labelrouge.html)**

- Seed or 'spat' oysters are purchased from dedicated hatcheries. They are available in a variety of size grades, usually from 4 mm – 30 mm shell length. The size grade quoted by suppliers generally refers to the size of mesh used to sort the oyster seed (3 – 14 mm mesh).
- Part-grown or 'half-ware' oysters may also be purchased from suppliers who specialise in this market. They are generally graded by weight and are usually sold at between 4 g – 15 g. Larger sizes can also be purchased. Oysters > 10 g are generally suitable for laying directly on to parcs as they are large enough to be safe from most predators.
- Where oysters are grown in bags to harvest, the size of the mesh in the bags is increased progressively as the oysters grow. Oyster seed between 4 – 8 mm shell-length is generally placed in 2 mm mesh bags. At 8 – 15 mm shell-length, 4 mm mesh is used. From 15 – 25 mm shell-length the bag is usually of 7 – 8 mm mesh and above 25 mm shell-length, 14 mm mesh is used. By final harvest the bags are generally of 18 – 25 mm mesh. As a general rule the largest mesh that will still retain all the stock is used as this promotes good water flow and optimises growth.

- The density of the stock within the bags is also reduced progressively as the animals grow. The dimensions of the bags vary between suppliers, but as a general guide stocking densities are approximately: up to 15 mm, 2 000 - 3 000 per m^2; > 25 mm, 1 500 per m^2; > 50 mm, 500 per m^2. Optimal stocking densities for best growth vary from site to site and must be determined by trials.
- The bags must be turned and the oysters redistributed every 2 weeks (spring tides) during the summer growing season and once a month or less (if very cold for instance) during the winter. Less intensive cultivation, i.e. at lower stocking densities, can reduce the need to turn the bags as space for optimal growth is not restricted. However, turning is still required to reduce fouling on the upper surfaces of the bags. In northern areas, it may not be necessary to disturb the stock during the winter, but they should be monitored in any event.
- Monitor the stock, thin, remove dead shells and transfer to larger mesh bags as required. Remove any predators and fouling as encountered.

4.3.3 Equipment

- Tractor and trailer (or equivalent) or boat for foreshore access and working. A boat or barge may be required for some sites.
- Other vehicles for road transport; Forklift for bulk handling.
- Oysters bags and trestles on which to support them
- Storage and dispatch facilities.
- Depuration facilities.
- Pressure washer; Weighing and grading machines etc.

4.3.4 Harvesting

- Stock may be harvested and marketed year-round. However, occasional problems with flesh quality, i.e. reduced condition, may occur in late summer if the oysters have spawned. Spawning may occur in southern England during very warm summers or at particular sites.
- The size at harvest varies between markets but is generally from 75 g upwards. It can take 2.5 – 3 years to first harvest although 2 years is achievable depending on the location and method of culture.
- At harvest the bags are removed from the trestles and transported to the processing plant. Here the stock is removed from the bags and washed which then allows dead shell to be discarded.
- Once cleaned, the stock is then graded into different sizes - this is usually by weight. Grading can be done automatically or by hand. Mechanised grading is faster, but it increases the stress on the oyster.
- Oysters are normally depurated before being sent to market. This can take place before or after grading and can be done in-house or contracted out. It may be required by the buyer even if the stock is from Class A harvesting waters.
- The stock should be packed into suitable containers for transport to market. This can vary from polystyrene fish boxes (for bulk) to decorative wooden punnets (point-of-sale display).
- Transport to market should be in chilled containers. Alternatively, the stock can be covered with ice as long as this does not come into direct contact with the oysters.

4.3.5 Suitability for Cultivation within the Proposed Lagoon

We consider intertidal Pacific oyster cultivation (within containment) to have a **High Technical Feasibility Potential** and a **Low Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 12.

We also consider that intertidal seabed Pacific oyster cultivation to have a **Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 13.

4.4 Native Oysters (*Ostrea edulis*)

Section 4.4 summarises the main techniques and conditions required to cultivate this native oyster species. *O. edulis* as a native species does not pose the same type of issues in terms of wild settlement as the Pacific oyster. The sources of hatchery or extensively reared seed are limited to diploid oysters and therefore any cultivation activities, within appropriate areas, that seek to increase potential broodstocks of this BAP species should be broadly welcomed in terms of their potential to help increase numbers of this now threatened species (Ref: Syvret and Woolmer, 2015).

4.4.1 Biology & Environmental Requirements

- Seawater temperatures above 8 – 9 ºC for much of the year are preferable for quickest growth.
- Salinity generally above 30 PSU in areas sheltered from extreme wave action or strong tidal flows.
- Tidal flow of 1 – 2 knots (50 - 100 cm per second) optimal, although less is acceptable. Avoid areas where the waters carry a very high silt burden as this can cause smothering.
- The longer the period of immersion the better the growth rate, although some exposure is required to promote shell hardness before harvest. Generally, the stock may just be submerged at extreme low water spring tides.
- Avoid areas where poor water exchange may result in oxygen depletion, particularly during warm weather. This can weaken or kill the stock.
- If exposed to the air during periods of cold winds and/or air temperatures close to or below freezing the oysters can die.

4.4.2 Cultivation Techniques

- Seed or ‘spat’ oysters may be purchased from a few dedicated hatcheries (see Figure 42). They are available in a variety of size grades, usually from 4 mm – 30 mm shell length. The size grade quoted by suppliers generally refers to the size of mesh used to sort the oyster seed (3 – 14 mm mesh). The prices are generally higher than those charged for Pacific oyster spat.

Figure 42: Hatchery produced native oyster seed (centre) shown alongside Pacific oyster seed. (Source: Aquafish Solutions Ltd.)

- Native oysters can be grown on the seabed or occasionally on ‘mats’ laid on very soft substrates. The seabed plots are often known as ‘parcs’. Alternatively, they may be grown successfully, particularly when small, in plastic mesh bags secured to metal trestles at the extreme edge of the intertidal zone. This method mirrors that used for Pacific oyster culture except that Pacific oysters can tolerate longer exposure times. High density culture has however proved to cause increased mortality rates on some sites where the parasitic disease *Bonamia ostreae* is found. More recently, native oysters have been grown successfully through to market size using the ORTAC system which is a more three-dimensional shellfish basket (see Figure 43).

Figure 43: Intertidal cultivation of native oysters using the ORTAC system. **(Source: Aquafish Solutions Ltd.)**

- Growth rates are reported to be excellent using the ORTAC system (see Figure 44) with low mortality rates (Tony Legg, Jersey Sea Farms, pers. comm.).

Figure 44: Seabed vs. intertidal cultivation of native oysters using the ORTAC system **(Source: Jersey Sea Farms)**

- A new containment culture system is also currently being trialled by Jersey Sea Farms specifically for native oyster cultivation. Called the 'Microreef' (see Figure 45) this system is based around a 'rack' that holds individual oysters in place to form a stack of oysters (15 g+). These stacks can then be placed within metal gabions in the intertidal zone. The Microreef concept could also be considered for suspension on buoyed headlines as part of a suspended cultivation system.

Figure 45: Cultivation of native oysters using the Microreef system. **(Source: Jersey Sea Farms)**

- Part-grown or 'half-ware' oysters may also be fished from the wild under licence. This stock is then relayed on to submerged on-growing beds and reared to harvest size. The lack of local available stock however means that this isn't likely to be a viable production method for the proposed lagoon.
- The optimal size for transfer to seabed plots will vary depending upon the predator profile of the area. In general, they will be larger than 25 – 30 mm shell length. Seabed plots must be monitored and managed to remove predators such as starfish.
-

4.4.3 Equipment

- Tractor and trailer (or equivalent) for foreshore access and working. A boat or barge may be required for subtidal sites.
- Other vehicles for road transport.
- Oysters bags and trestles on which to support them.
- Storage and dispatch facilities.
- Depuration facilities.
- Weighing and grading machines; Packing systems; Stock handling systems.

4.4.4 Harvest

- Native oysters are traditionally only harvested when there is an 'r' in the month i.e. from September to April. This avoids the periods when they are spawning or retaining their young and meat quality is at its lowest.
- Size at which harvest takes place varies between markets but is generally 75 g upwards. It can take 3 – 4 years to first harvest, depending on the location and cultivation system.
- If the stock is in bags, they are removed from the trestles and transported to the processing plant. The stock is removed from the bags, washed (to remove mud, fouling etc.) and the animals are separated as necessary before grading.
- Seabed cultivated stocks are traditionally harvested by a variety of bottom dredges. Some growers may hand-gather the stock to enhance quality. Once at the processing plant they are treated in the same way as bag-grown stock.
- Post-harvest the stock is sorted into different grades - this is usually by weight. This can be done automatically or by hand.
- Depuration can take place before or after grading. This can be done in-house or contracted out and may be required by the buyer even if the stock is from Class A waters.
- The stock should be packed into suitable containers for transport to market. This can vary from polystyrene fish boxes (for bulk) to decorative wooden punnets (point-of-sale display).
- Transport to market should be in chilled containers. Alternatively, the stock can be covered with ice as long as this does not come into direct contact with the oysters.

4.4.5 Suitability for Cultivation within the Proposed Lagoon

We consider intertidal native oyster cultivation (within containment) to have a **High Technical Feasibility Potential** and a **Low Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 9.

We also consider that intertidal seabed native oyster cultivation to have a **Moderate Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 10.

4.5 Cockles (*Cerastoderma edule*)

Section 4.5 provides a general overview of cockle cultivation (see Figure 46) covering the techniques and conditions required for successful cultivation.

Figure 46: Wild caught cockles, Cerastoderma edule. **(Source: MarLIN – The Marine Life Information Network)**

It should be noted that cockles are not widely cultivated but have been grown successfully in trials and are currently in short supply due to the unexplained mass cockle mortalities in recent years. There are currently plans to trial cockle cultivation within dikes on Texel in the Netherlands as part of a mitigation strategy to deal with salt intrusion which is being exacerbated by climate change and rising sea levels. For further details see the following; https://www.royalhaskoningdhv.com/en-gb/projects/promising-future-for-cockle-farming-inside-the-dike/1463

4.5.1 Biology & Environmental Requirements

- Cockles are tolerant to a wide temperature range (7 °C – 34 °C) with optimum temperatures for growth falling in the middle of this range. Seawater temperatures above 8 – 9 °C for much of the year are preferable for quickest growth.
- Salinity should be above 15 PSU and up to 30 PSU in areas sheltered from extreme wave action or strong tidal flows.
- Tidal flows of 1 – 2 knots (50 - 100 cm per second) are optimal, although less is acceptable.

4.5.2 Cultivation Techniques

- Limited culture activities have taken place on the south coast of England on managed beds and thus is included in this section for completeness.
- Seed cockles for on-growing are generally sourced from wild productive cockle areas where nutrient levels can be sub-optimal thus limiting growth rates. An example of such an area is the Thames Estuary. These seed cockles are thus harvested, transported and then re-laid onto the managed beds.

- Seed cockles should be harvested using a low impact harvesting system such as the eco-harvester so as to minimise shell damage. Transport is normally in bulk bags and at a time at which exposure to low air temperatures is avoided.
- Cockle seed can be produced within hatcheries but this would normally be to order.
- After re-laying on a managed bed, the cockles will take around 18 months to reach a marketable size.

4.5.3 Equipment

- Cockle culture would be best carried out using similar techniques and equipment to that described for ranching of Pacific oysters i.e. use of aquaculture barge with an elevator dredge fitted with a fluidising head. The fluidising head injects water under high pressure into the substrate surface and thus removes the shellfish.
- Other vehicles for road transport.
- Storage and dispatch facilities.
- Depuration facilities.
- Weighing and grading machines.
- Packing systems.

4.5.4 Harvest

- In good growing conditions harvest of cockles normally takes place after approximately 18 months.
- Harvesting can be carried out using an eco-harvester which has a minimal environmental impact when compared to many dredge types.
- After harvesting the cockles will need to be processed in order to remove dead shell, debris and mud.
- Depuration should take place as soon as possible after harvesting (within 6 hours). Depuration costs with cockles are higher owing to the fact that re-use of seawater is not allowed when depurating cockles.

4.5.5 Suitability for Cultivation within the Proposed Lagoon

We consider intertidal seabed cockle cultivation to have a **Low Technical Feasibility Potential** and a **High Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 18.

4.6 Mussels (*Mytilus edulis*)

Section 4.6 provides a general overview of mussel cultivation utilising the French technique of cultivating mussels intertidally on Bouchot poles.

4.6.1 Biology & Environmental Requirements

- Mussels are tolerant to a wide temperature range (2.5 °C – 19 °C) with optimum temperatures for growth falling in the middle of this range.
- Salinity should generally be above 20 PSU and up to 30 PSU in areas sheltered from extreme wave action or strong tidal flows.
- Tidal flows of 1 – 2 knots (50 - 100 cm per second) are optimal, although less is acceptable.

4.6.2 Cultivation Techniques

- The Bouchot pole cultivation system is widely practised in France.
- With this system, hardwood posts are driven into the substrate by mechanical means.
- Mussel lines are wrapped around the posts and nailed in place.
- Mussels are periodically graded and reattached in order to maintain an optimum stocking density.
- Depending on the prevailing exposure, the mussels may be kept contained within socking which can be biodegradable (cotton) or can remain permanently in place (nylon).

4.6.3 Equipment

- Hardwood posts driven into the substrate and arranged in rows for ease of harvesting (see Figure 47).
- Rope mussel socking (nylon or cotton).
- Other vehicles for road transport.
- Storage and dispatch facilities.
- Depuration facilities.
- Weighing and grading machines.
- Packing systems.

Figure 47: Bouchot poles with mussels attached. **(Source: Aquafish Solutions Ltd.)**

4.6.4 Harvest

- Harvest of Bouchot mussels normally takes place after approximately 18 months to 2 years in good growing conditions.
- Harvesting can be carried out by hand or by use of specialised harvesting boats.
- After harvesting the mussels will need to be processed in order to remove byssus thread, dead shell, debris and mud.

4.6.5 Suitability for Cultivation within the Proposed Lagoon

We consider intertidal Bouchot mussel cultivation to have a **High Technical Feasibility Potential** and a **Low Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 6.

SECTION 5 – MACROALGAE / SEAWEED CULTIVATION OPTIONS FOR TIDAL LAGOONS

5.1 Introduction

Section 5 of the current report summarises the overall potential for macroalgae cultivation within the proposed tidal lagoon at Swansea Bay. This review of macroalgae cultivation does not form part of the main project scope but is included in order to give an overview of other mariculture activities that might be considered in addition to the cultivation of bivalve shellfish.

Section 5 reviews previous work by Syvret *et al.* (Ref: 2013) when looking at potential mariculture co-location within offshore wind farms together with a report that was prepared by SAMS Research Services Ltd. (SRSL) in 2015 when considering the potential for macroalgae cultivation within a possible tidal lagoon at Cardiff (Ref: Kerrison and Hughes, 2015). Whilst the environmental conditions in the upper reaches of the Severn Estuary are very different to that of Swansea Bay (e.g. high suspended solid loading with consequent high turbidity) the Cardiff Lagoon report is still relevant to the potential for macroalgae cultivation within these types of marine renewable energy structures. Finally, the cultivation of *Porphyra*, known locally as Laverbread, is considered in more detail based on work carried out by the Algal Biotechnology for Wales KTC for Salacia Marine (Ref: Powell, 2011).

5.2 Uses of Macroalgae / Seaweeds

Seaweeds are the largest volume aquaculture product in the world due to their diverse uses, which vary between different species. Many species are cultivated for high value use as a food, particularly in East Asia where they are a dietary staple. Many are also cultured for lower value industrial bulk chemicals, particularly gelling agents, which have major applications in the food, manufacturing and cosmetic industries. Seaweeds and their extracts are also used in animal feed and as fertiliser in agriculture and horticulture. Due to their particular chemical compositions, some species can be of value to extract other commercially valued fine chemicals such as iodine and mannitol, both found in large quantities in the large leathery kelps.

In addition, due to the high carbohydrate content and fast growth in some species, large-scale cultivation could be used to produce biofuel as part of a carbon neutral economy. Bioprospecting of seaweeds is also currently underway for the development of new drugs. Extracts with specific chemicals have been found with anti-inflammatory, anti-cancer activities, to name a few. These developments could lead to high value applications for specific seaweed species in the near future (Ref: Kerrison and Hughes, 2015).

5.3 Production Levels and Techniques

There have been numerous studies looking at the technical aspects of offshore macroalgae culture. Buchholz *et al*. (Ref: 2012) cite Buck *et al*. (Ref: 2008) as a review paper in this respect. Macroalgae have proved to be suitable candidates for offshore culture and can exhibit morphological adaptations to these higher energy environments.

System designs utilised for macroalgae culture have varied from long-lines similar to that used for rope-mussel cultivation (see Section 3.5.4) through to designs created specifically for macroalgae culture, such as the offshore-ring structure developed by the Alfred Wegener Institute shown in Figure 48.

Figure 48: Offshore-ring system for macroalgae culture shown with fully grown Laminaria saccharina. **(Ref: Buck and Buchholz, 2004)**

Buck and Buchholz (Ref: 2004) report that this system has been successfully tested in the North Sea approximately 3.5 miles off the German coast. The ring is said to have withstood strong current velocities and wave heights associated with rough sea conditions. A schematic of the ring design (Patent DE 10 2004 010 652) is shown in Figure 49.

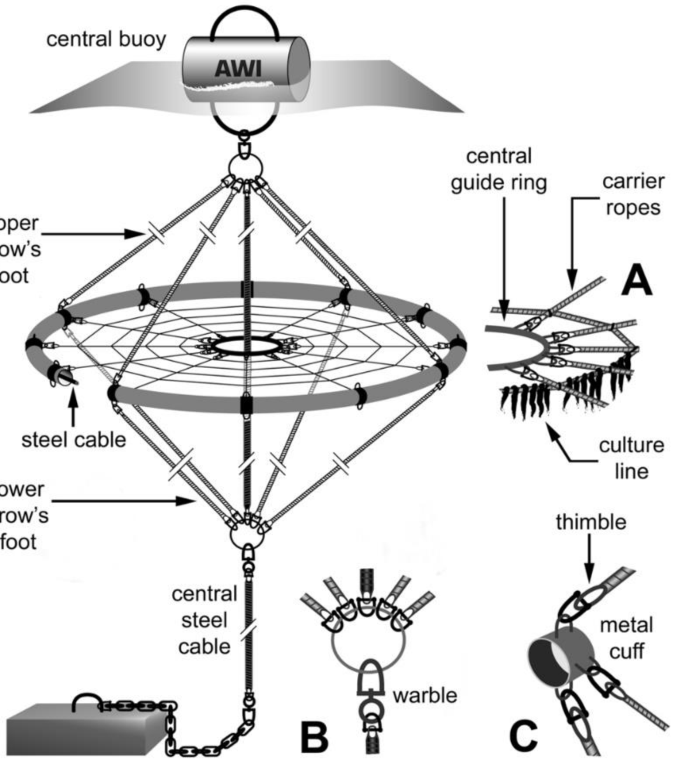

Figure 49: Schematic of the AWI offshore-ring macroalgal culture system. *(Ref: Buck and Buchholz, 2004)*

The macroalgae is held on a culture line located between 1 to 1.5 m below the sea surface on an outer ring-structure of 5 m in total diameter. At this depth, the macroalgae are protected from wave motion induced damage or excessive UV radiation whilst still being able to actively photosynthesise.

Another macroalgae system has been tested 9.5 km off the Dutch coast in collaboration between a renewable energy consultancy, Ecofys, and the NL Agency a division of the Dutch Ministry of Economic Affairs, Agriculture and Innovation. The intention is to see if this system (see Figure 50) could be co-located with offshore wind farms to provide an additional revenue stream from the same marine area through the production of high-value food products.

Figure 50: Ecofys macroalgae system shown at launch and on-site in Dutch waters

The innovative seaweed cultivation module, which measures 20 by 20 m, consists of a set of steel cables, held two metres under the sea surface by anchors and floating buoys. Horizontal nets measuring 10 by 10 m are suspended between the cables to which the macroalgae are attached.

There are other pressing needs for research if large-scale offshore macroalgal culture is to become economic. Dunningham and Atack (Ref: 2012) report that whilst the current labour intensive seeding systems may remain economic for the higher value macroalgae products, much more industrial-scale and efficient seeding systems will be required if macroalgae for biofuels is ever to become economic.

5.4 Economics and Markets

It is estimated that worldwide in 2014, aquatic plant production, primarily seaweeds, stood at 27.3 million tonnes and was valued at US$5.6 billion of which the main value is related to products destined for human consumption (Source: FAO). Examples of edible seaweed species include Undaria (for food 'wakame' in Japan), Gracilaria (for food and agar production) and Porphyra which all fetch good market prices.

Economic feasibility studies have reported that strong markets exist for brown and red algae (Ref: Buck et al., 2008). Algae can be utilised for food markets as a healthy and 'green' biofood or utilised in other industries as an emulsifier, medicine or subsidiary ingredient in foods (Ref: Buck et al., 2008). The use of seaweed for nutrient scrubbing also shows promise and there are now a number of schemes elsewhere in the world where both seaweed culture and shellfish culture are used to mitigate nutrient loads to the marine environment using a system of N credits.

Buck and Buchholz (Ref: 2004) considered seaweed culture in high energy Northern European waters using offshore-ring structures to provide a more stable platform than conventional long-lines. Although the technology was successful the potential income from seaweed production was €40 per ring whilst the initial capital cost was €100 per ring (assuming 10 year depreciation). This production cost does not include operational costs let alone an allowance for the loss of systems within the 10 year payback period.

In terms of energy production, the seasonality and variable quality of macroalgae does pose considerable operational issues. Conventional seeding of seaweed germlings in the early spring will only generate harvestable biomass in the later summer/autumn of that year. This does not therefore provide a continuous supply of raw material throughout the year to energy production applications, an issue if it is used as the sole source of material for biofuels.

In economic terms, BioMara has reported that, as a standalone commercial venture, using seaweed for energy generation is marginal at current energy prices (Source: http://www.biomara.org/news/summer-2012-newsletter-published). Lewis *et al*. (Ref: 2011) also reported that fermentation of seaweed to ethanol is not currently an economic process and that anaerobic digestion based on plants fed only with seaweeds does not look favourable on either a small or large-scale. They estimated that the cost of seaweed necessary to allow an economically viable anaerobic digestion process would need to be of the order of £100 to £300 per dry tonne delivered, which is in agreement with Roesijadi and Huesemann (Ref: 2008) who described an equivalent biomass cost of corn at US$250 per metric tonne delivered (equivalent to approximately £145 at 2008 exchange rates). To put this in context, even ignoring drying and delivery costs, the figures given by Lewis *et al*. (Ref: 2011) equate to a price in wet weight terms of £0.01 to £0.03 per kg which is not currently achievable using existing technology for a cultivated product. Commercial-scale pilot trials would help greatly in identifying the true costs of production and likely levels of offshore production of these edible macroalgae. This would then in turn allow a proper economic evaluation of the production of these species (Ref: Syvret *et al*., 2013).

Looking specifically at *Porphyra*, Powell (Ref: 2011) reports that around the Bristol Channel, the predominant UK species, *Porphyra umbilicalis*, is ubiquitous on rocky coasts and is commercially collected where it is used to make laverbread. UK demand for laverbread is stated as being small but constant. There is also a demand for *Porphyra* as an ingredient in high quality "white tablecloth" restaurants whilst the increase in numbers of sushi restaurants across Europe has increased *Porphyra* demand. There is also a demand in South Wales for *Porphyra* as an ingredient in snack products (see http://www.selwynsseaweed.com/). The scale and value of *Porphyra* to the Welsh economy is probably in the tens of thousands of pounds and volume in the tens of tonnes per year (Ref: Powell, 2011).

Power (Ref: 2011) states that whilst nori farming is the subject of experimentation in western countries, they are not likely to become major producers as the activity is labour intensive and highly seasonal. A combination of innovation, cultivation and niche markets may lead to future success for investors in *Porphyra* cultivation, rather than attempts to break into the large and well supplied overseas markets for nori, kombu and wakame. Inclusion in products such as Selwyn's Seaweed Snacks would seem to fit this model.

In summary, at least in the short to medium term any consideration of macroalgal cultivation within tidal lagoons should be targeted at those species that can be used to supply the market for high-value products such as that for food. As such, the remainder of Section 5 of this report will concentrate on *Porphyra* as a high value local species with proven commercial use.

5.5 Overview of Macroalgal Cultivation Potential within the Proposed Lagoon

This report assesses the feasibility of using the proposed Swansea Bay tidal lagoon for the cultivation of seaweeds of high economic value. There are three possible environments within a tidal lagoon that could be considered for seaweed cultivation: the intertidal, subtidal and on the tidal breakwater (see Figure 51).

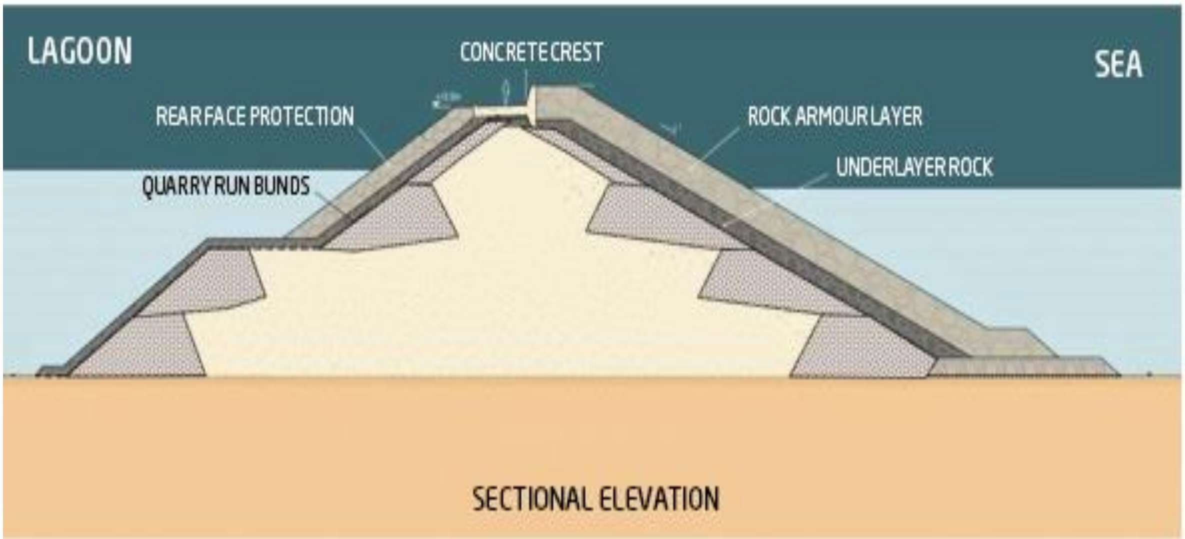

Figure 51: Possible design for the tidal breakwater of TLSB

(Source: Tidal Lagoon Swansea Bay)

Each of these environments has been examined individually, with the feasibility of seaweed cultivation assessed, and any gaps in knowledge identified (Ref: Kerrison and Hughes, 2015).

5.6 Assessment of Intertidal Area

5.6.1 Suitability for Macroalgae / Seaweed Cultivation

The intertidal area provides a good opportunity for seaweed cultivation although at present TLSB are unable to define the extent of the intertidal area that would be created after the lagoon has been constructed.

An established method for seaweed cultivation is to drive fixed vertical piling into soft substrates, and then string ropes or nets between them. Seaweed is then seeded directly onto these ropes and nets, or pieces are placed into the twist of the ropes. These ropes would be fully exposed at low tide, and so only highly desiccation resistant species could be cultured. A suitable species for this cultivation technique could be *Porphyra* spp. This species grows as thin, fast growing sheets, tolerant to very high light and desiccation. It has high value as a food; used to make nori sheets or the local Welsh delicacy known as laverbread.

It is however unknown at present whether *Porphyra* can be grown in commercial quantities within the intertidal area of the proposed lagoon. The physicochemical characteristics of the water body will need to be determined, namely salinity, temperature and nutrients (Ref: Kerrison and Hughes, 2015). Turbidity levels in terms of light penetration and suspended solid levels in terms of the potential for smothering are also important.

Powell (Ref: 2011) states that for *Porphyra*, some rain is an advantage, since it brings nutrients via run-off but low salinities can be deleterious as this reduces disease resistance. However, initial indications are (see Matrix Row 20) that the lower intertidal environment within the lagoon may be suitable for *Porphyra* cultivation as long as turbidity and suspended solid levels are not too high.

Due to its morphology, *Porphyra* can only be grown at low densities on the nets (1 - 3 kg per m^2) and harvesting would be labour intensive. It is usually grown on nets (see Figure 52) in calm areas and harvesting is performed every three weeks and can be mechanised to improve profitability (Ref: Kerrison and Hughes, 2015).

Figure 52: Intertidal Porphyra farming in Japan. **(Source: genderaquafish.org – left hand image / FAO – right hand image)**

Since the final biomass of *Porphyra* only has value as a food, other characteristics of the water quality would be very important. In particular, the concentrations of faecal coliforms and possibly also suspended solids should be examined (Ref: Kerrison and Hughes, 2015). Modelling of *E. coli* levels carried out by Intertek, as described in Section 1.2.5, would indicate that the Classification for shellfish harvesting purposes may be as high as Class A. This would seem to indicate therefore that water quality within the lagoon would be sufficiently high to consider the cultivation of macroalgae for human consumption.

5.6.2 Conclusions Regarding Intertidal Area

There is a potential area within the intertidal zone of the proposed lagoon available for macroalgae cultivation although this would require trials to see if cultivation is feasible. *Porphyra* cultivation may be possible, but its potential for successful growth at this location needs to be confirmed by examination of various water parameters. If these parameters were to prove adequate (e.g. low turbidity and no smothering effects through suspended solids) then we consider intertidal *Porphyra* cultivation on nets to have a **High Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 20.

5.7 Assessment of Subtidal Area

5.7.1 Suitability for Macroalgae / Seaweed Cultivation

It is unknown at present whether *Porphyra* can be grown in commercial quantities within the subtidal area of the proposed lagoon. The physicochemical characteristics of the water body will need to be determined, namely salinity, temperature and nutrients (Ref: Kerrison and Hughes, 2015). Turbidity levels in terms of light penetration and suspended solid levels in terms of the potential for smothering are also important. However, initial indications are (see Matrix Row 20) that the subtidal environment within the lagoon may be suitable for *Porphyra* cultivation as long as turbidity and suspended solid levels are not too high.

Seaweed cultivation would be most favourable in areas with rapid water exchange. This will refresh nutrients and reduce the settlement of suspended sediment that could smother the growing seaweed. The best location for cultivation would be the areas near the turbines and to the west of the lagoon where the flow speed will be highest. Areas where the flow speed are reduced will have low levels of suitability. Ongrowing of *Porphyra* can be carried out on floating or semi floating nets. Both floating systems require the nets to be attached to buoys or rafts and then placed in water deep enough to allow constant immersion, or in shallower waters allowing emersion at low tides. Periodic exposure potentially reduces growth but also reduces the incidence of disease and epiphytic competition (Ref: Powell, 2015).

A foreseeable problem is the hypertidal range in the area of nearly 8.5 m between MHWS and MLWS. This may present problems in the mooring of any floating cultivation system, including that for bivalve shellfish. To keep the system placed, the mooring lines would need to be long, with extensive lengths of ground chain. This may present engineering issues, expense issues and issues associated with co-location of existing uses such as conservation, yachting, commercial fishing and recreational angling (Ref: Kerrison and Hughes, 2015). It is possible that the use of screw anchors with an attachment shaft protruding above the surface (see Figure 22) may help to overcome these issues. Other alternative solutions could include anchor/mooring systems with flexible/extending risers.

5.7.2 Conclusions Regarding Subtidal Area

There is a potential area within the subtidal zone available for macroalgae cultivation although this would require trials to see if this form of cultivation is feasible. The areas within the lagoon with the highest water flow would be the most suitable as cultivation areas. However, the large tidal range may make mooring the cultivation lines more expensive and problematic than in other areas with a lower tidal range. *Porphyra* cultivation may be possible, but its potential for successful growth at this location needs to be confirmed by examination of various water parameters and by investigation of the practical aspects of providing suitable moorings etc. that can work within the expected tidal ranges of the lagoon. If these parameters were to prove adequate (e.g. low turbidity and no smothering effects through high levels of suspended solids) then we consider subtidal *Porphyra* cultivation on nets suspended from long-lines to have a **High Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors** (based on current knowledge and therefore subject to change). Please refer to Matrix Row 20.

5.8 Assessment of Breakwater Site

5.8.1 Suitability for Macroalgae / Seaweed Cultivation

A further possibility offered by Kerrison and Hughes (Ref: 2015) for tidal lagoons is that the breakwater itself could be used as a cultivation area. With an almost 11 km length the breakwater would provide an expansive new intertidal region. The hypertidal range of the area should provide good water motion, so preventing the settlement of sediment onto any cultured species, a problem that might be experienced with intertidal cultivation. Due to the wave protection provided by the breakwater, the lagoon side should have a more sheltered environment for cultivation activities and so may be particularly suitable.

In terms of cultivation systems, Kerrison and Hughes (Ref: 2015) report that fixed pilings could be mounted on blocks within the rock armour, and could be used to provide a large area for the mounting of ropes or nets, both in the intertidal and subtidal. Therefore, potentially, many different seaweed groups could be cultivated. Another alternative is that synthetic tide pools could be created within the breakwater rock armour. These could potentially be used for the cultivation of species such as *Ulva*. We are unaware of any other development considering this dual-use and so it could be a globally unique proposition.

Kerrison and Hughes (Ref: 2015) state that there could be considerable advantages in using the breakwater over both intertidal and subtidal cultivation. These are summarised as follows:

Ease of access; It would not be necessary to access the cultivation area via an intertidal substrate or by boat for subtidal systems. Instead, access could be via the man-made breakwater subject to an assessment of safe working practises. This would substantially reduce the cost compared to intertidal or subtidal cultivations.

Environmental impact; Both intertidal and subtidal cultivation will impact the ecosystem in which they are placed, and intertidal cultivation will have a visual impact on the nearshore. If a new ~11 km breakwater is being built, then this can be considered a ‘new’ intertidal environment, so its utilisation for seaweed cultivation will not replace an existing ecosystem. This approach would also have less impact on current environmentally designated features.

Environmental responsibility; By making the breakwater itself a seaweed cultivation area, it may be viewed more favourably by the public and environmental groups, since you are creating economically useful habitat.

A possible complication to adopting breakwater cultivation could be the relatively steep angle of the breakwater and that the rock armour will not be entirely stable. It is likely that these can be avoided with careful forethought. However, this may require the barrier design to be amended with this use in mind, which is something that would need to be considered early on in the engineering plans (Ref: Kerrison and Hughes, 2015).

5.8.2 Conclusions Regarding Breakwater

The use of the intertidal zone on the breakwater itself holds excellent opportunities for development of seaweed cultivation. The unique development could reflect favourably on both the tidal lagoon and seaweed cultivation industry through collaboration. However, the idea requires further development to determine the best form it would take (Ref: Kerrison and Hughes, 2015). We consider breakwater cultivation of seaweed to have a **High Technical Feasibility Potential** and a **Moderate Risk level due to environmental factors**. Please refer to Matrix Rows 20 to 22).

5.9 Knowledge Gaps

To fully assess the feasibility of using the proposed tidal lagoon at Swansea Bay for seaweed cultivation, more detailed information is necessary on the physicochemical characteristics of the water body, and how these will be affected by the tidal lagoon creation. The tolerance of different seaweed species to these parameters will dictate which can be cultivated but this may well include *Porphyra*. In addition, data on light penetration with depth is necessary, levels of suspended solids and the concentration of faecal coliforms (and water quality assessment in general) will be needed if the seaweed is ultimately destined for human consumption (Ref: Kerrison and Hughes, 2015).

SECTION 6 – SPATIAL PLANNING TOOLS TO SUPPORT AQUACULTURE DEVELOPMENT

6.1 Introduction

Site managers such as tidal lagoon operators, port managers and bodies developing Aquaculture Parks, regulators involved in the consenting process, and aquaculture businesses face series of challenges in relation to the siting of aquaculture operations.

The operational envelope for any aquaculture métier is dictated by the ecological needs of the species and by the physical operational requirements of the equipment employed. Combined, these constraints define where individual aquaculture métiers will be viable and can be sited. The challenge for developers is to readily access site information in order to identify suitable sites and de-risk site selection.

The coastal zone, and particularly sheltered water bodies and especially ports, are busy places with multiple human activities operating in the same spatial footprint and not all are compatible with aquaculture. The available space for aquaculture developments within these areas is becoming increasingly limited with new activities including recreational activities and renewable energy generation competing for access and space. Tidal lagoon operators face similar challenges to locate aquaculture operations having to account for the operational constraints of their core energy generation activities in order to avoid risks of damage to infrastructure. The TLSB have envisaged a multiuse lagoon that combines recreational and educational activity alongside aquaculture and energy generation. In the wider coastal zone, competition for space may also come from traditional wild capture fisheries and existing recreational activities. The challenge for developers and managers alike is to identify areas in which to site aquaculture activities that avoid conflict and displacement of traditional activities, and to determine where co-location opportunities exist.

Coastal waters, and particularly embayments and estuaries, contain a variety of sensitive habitats and species that may be impacted by aquaculture activities. Many areas in the coastal zone are subject to a mosaic of spatial nature conservation designations such as EU Special Areas of Conservation and national Sites of Special Scientific Interest. Even man-made sites need to consider the effects of associated activities on the natural environment. The TLSB development has described in its Environmental Statement the provision for a “quiet area” as a mitigation measure to prevent wading bird disturbance. The challenge for developers and managers is to understand where sensitive habitats and species occur in order that aquaculture developments can be sited sensitively and avoided where risk of disturbance exists.

As Sanchez-Jerez (Ref: 2016) highlight, “..the complex interactions among users of coastal areas often leave little space for aquaculture, particularly since marine aquaculture requires coastal waters with specific environmental and water quality characteristics.”

6.2 Spatial Analysis Tools

The development and adoption of spatial analysis tools offer the aquaculture industry a means to facilitate sector growth by identifying potential areas for development, de-risking site selection and avoiding conflict with other sea users and industries. Sensitive siting enabled by these tools can ensure that sensitive habitats and species can be afforded the protection that they require.

6.2.1 Examples of Existing Spatial Tools for Aquaculture

The use of spatial tools such as GIS and, more recently web-based tools, has become commonplace in the development of Marine Plans as a result of the devolved administrations’ new approach to managing the seas around the UK (see the following for information on Marine planning in England: https://www.gov.uk/government/collections/marine-planning-in-england). The development of Marine Plans has resulted in regional scale spatial analysis being undertaken to determine the potential for aquaculture in some areas.

6.2.1.1 Spatial Trends in Aquaculture Potential – South and East Marine Plans

The MMO report (Ref: 2013) entitled "Spatial trends in aquaculture potential in the South and East inshore and offshore marine plan areas" describes the development of a model that attempts to reconcile the ecological and operational constrains to a suite of aquaculture methods with an assessment of economic viability and environmental constraints. This model was able to describe in broad terms the potential spatial footprint in which different aquaculture activities could be developed with a weighting for proximity to existing ports and infrastructure (see Figure 53).

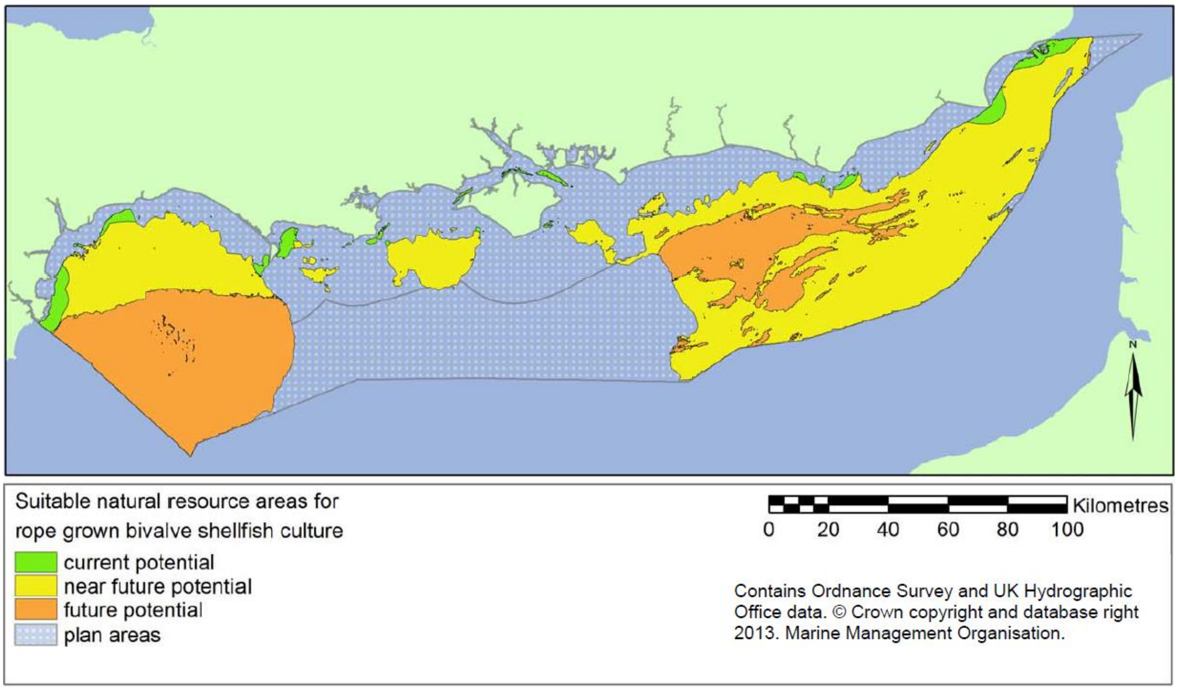

Figure 53: An example of the MMO/MPC rope mussel spatial model for the SE marine plan area (Source: MMO/MPC, 2013)

The planning and infrastructure constraints likely to influence the development of new aquaculture operations were presented in an additional spatial analysis in the Spatial Trends project. The project developed a series of GIS analysis assessing the levels of conflicting activities and prohibited areas that would affect each aquaculture method in each Marine Plan area. These activities included recreational activities such as yacht racing courses and dive sites as well as existing aquaculture and fisheries, historic sites such as wrecks, Natura 2000 sites and other wildlife sites, and discharges. A series of exclusion areas were developed that describe the location of sites considered incompatible with aquaculture production:

- Protected wrecks.
- IMO shipping routes.
- Oil and gas infrastructure.
- Wave and tidal lease areas.
- Offshore wind (bottom culture only).
- Aggregate production and application areas.
- Prohibited areas for harvesting (shellfish only).
- Existing aquaculture sites (including Several and Regulatory orders).
- Dredge disposal grounds.
- Ship-to-ship transfer areas.
- Anchorage/safe refuge sites.

It is likely that these exclusion areas will be simiar for many regions in the UK and it is expected to be expanded to reflect other activities. An example of the constraints analaysis is presented in Figure 54.

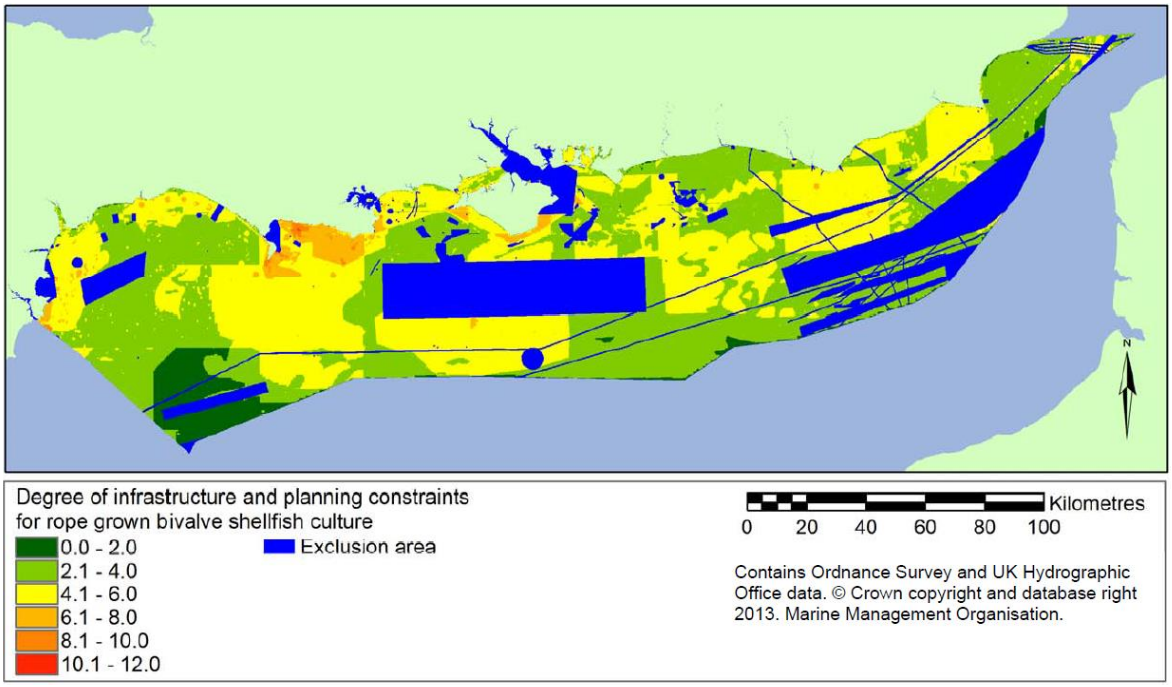

Figure 54: An example of the infrastructure and planning constraints in the South Marine Plan Areas for rope grown bivalve shellfish culture (Source: MMO/MPC, 2013)

6.2.1.2 Potential Marine Aquaculture Sites in Welsh Marine Waters

A recent study for Welsh Government (Ref: ABPmer, 2015) to inform the development of the Welsh National Marine Plan aimed to assess the potential for aquaculture within the Welsh Marine Plan areas.

This study aimed to highlight locations of opportunity for potential future marine aquaculture developments over the subsequent 20 years (i.e. up to 2035). This study developed a spatial model extending from the shore to 12 nm (the Welsh Inshore Marine Plan Area – see Figure 55).

The spatial model considered three 'core components' relating to:

- Natural resource constraints (e.g. water depth, substratum, temperature etc.);
- Marine Spatial Planning (MSP) constraints (e.g. nature conservation designated sites, areas of other marine industry activity, infrastructure and exclusion zones, recreational activity etc.); and
- Investment dependent constraints (e.g. Proximity to landing ports, depuration facilities, and invasive non-native species (INNS)).

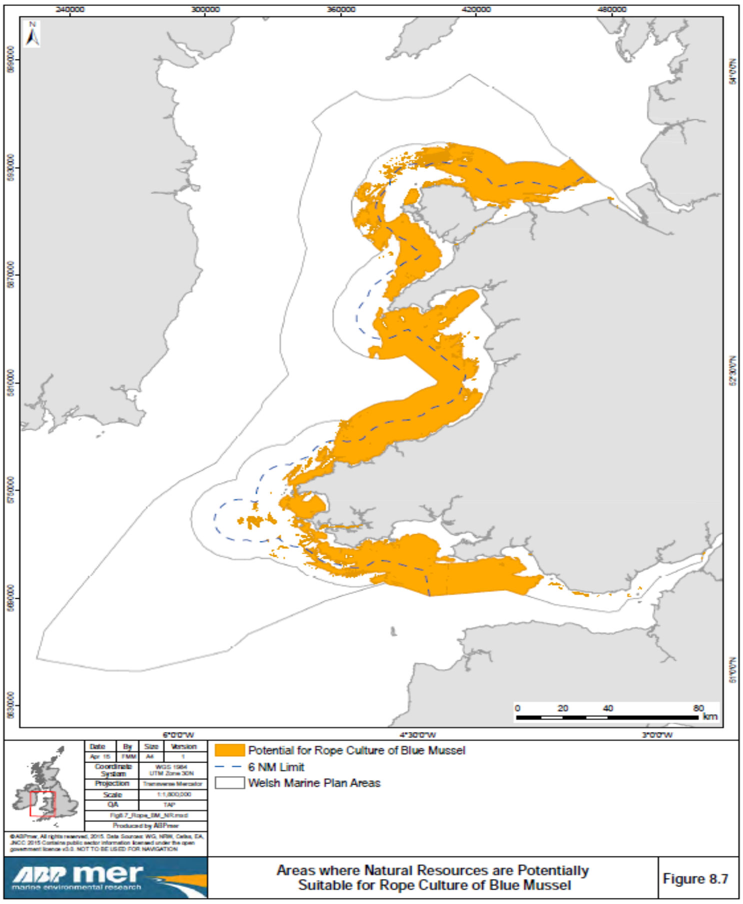

Figure 55. An example of the Welsh rope mussel spatial model for the Welsh Marine Plan Area (Source: ABPmer, 2015)

The model developed for the Welsh study attempted to identify locations for aquaculture species and methods that are currently undertaken in Wales and, acknowledging the potential for innovation, also included novel species and methods such as macroalgae culture.

The Welsh model combined multiple data layers overlaid to identify areas with the least or no constraints to aquaculture development (see Figure 56).

This study assigned 'exclusion areas' to areas where existing or planned activities and/or infrastructure was judged to be incompatible with aquaculture. These included:

- Marine renewables – wave and tidal lease areas (Note: excluding any offshore windfarms or areas under consideration for potential tidal lagoon schemes, due to potential for co-location);
- Oil and Gas – platforms and pipelines;
- Subsea cables;
- Marine aggregates – application areas, licence areas;
- Shipping – International Maritime Organisation (IMO) Traffic Separation Schemes;
- Ports and harbours – anchorage points, anchorage areas, navigation channels, open dredge disposal sites;
- Historic protected sites – protected wreck exclusion zones;
- Consented discharges – combined storm overflows;
- INNS – known presence of *Didemnum vexillum*; and
- Aquaculture – current businesses.

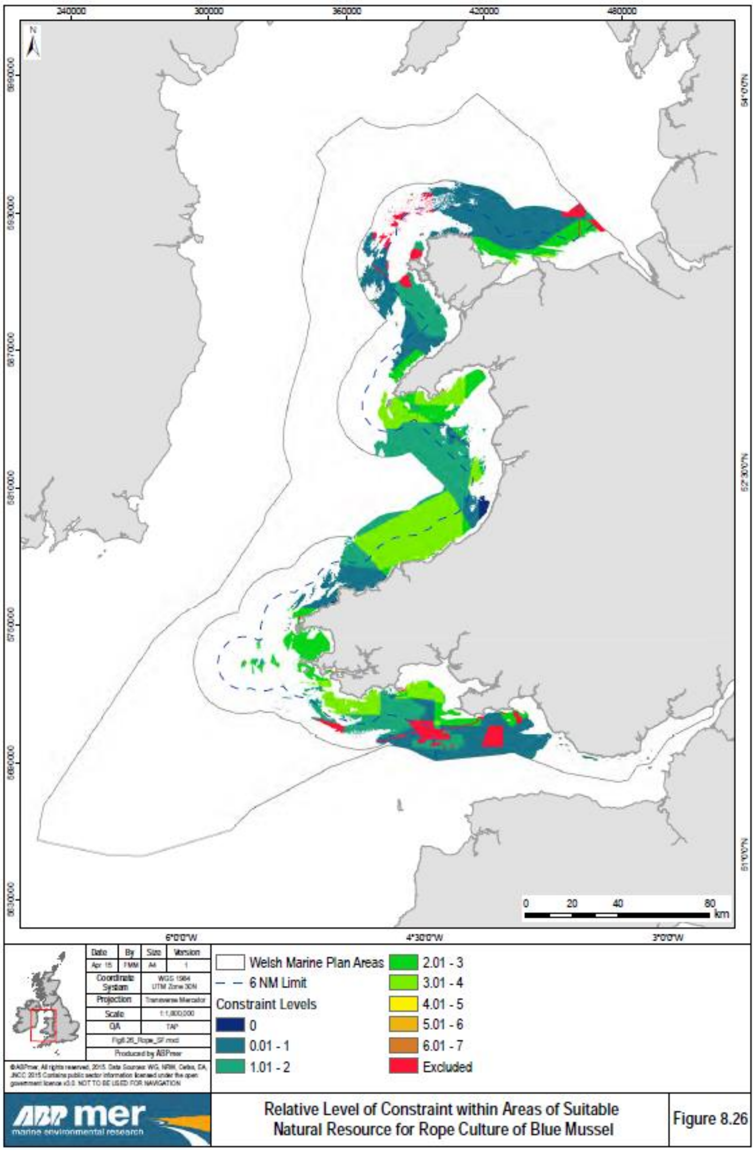

Figure 56. An example of the infrastructure and planning constraints in the Welsh Marine Plan Areas for rope grown bivalve shellfish culture (Source ABP, 2015)

6.2.1.3 Wales Marine Planning Portal

The Wales Marine Planning Portal (http://lle.gov.wales/apps/marineportal/) has been developed by Welsh Government as a means of publishing a wide range of marine data required to facilitate the high level of stakeholder engagement required for marine planning. The Portal was designed to provide a straightforward method for stakeholders to feed information about uses of the marine environment into the marine planning process.

In terms of functionality, the Portal has been structured to allow additional or updated layers to be added with the minimum of effort or technical expertise. The online mapping process is simplified through a click box menu interface that enables users to select layers from the background layer database. The database contains and controls the full range of relevant information and data such as, copyright, metadata, layer guidance notes, and map template production.

The portal can currently present spatial data, termed Strategic Resource Areas (SRAs):

- Governance boundaries e.g. 3 nm, 6 nm and 12 nm limits.
- Natural resources (ecological) including seabed and foreshore habitats.
- Bathing waters.
- Cultural resources such as protected wrecks and LANDMAP assessments https://naturalresources.wales/planning-and-development/landmap/?lang=en
- Protected areas (nature conservation).
- Defence and national security areas such as military practice areas and firing ranges.
- Energy production and infrastructure sites including sites of existing developments but also including areas of potential development.
- Port locations and shipping activity mapping including aggregated AIS data.
- Marine aggregate activity including areas of exploration.
- Fishing layers describing the general areas of current fishing activity.
- Aquaculture related layers include outputs of the Potential Marine Aquaculture Sites modelling study described previously, the current shellfish waters designations and FSA shellfish classification for currently classified areas.
- Tourism and recreational activities including the locations of angling sites and water sports areas.
- Cables, pipelines and waste layers present the location of submarine cables and pipelines, and discharge sites.
- Human-use coastline structures such as seawalls.
- Human-use areas or zones layers include a variety of licensing and areas subject to management plans.
- Information from the Wales Coastal Directory presents the contact details for local sectoral bodies and key contacts for consultation.

The aquaculture layers presented in the portal have been derived predominantly from the ABPmer report (Ref: 2015), 'A Spatial Assessment of the Potential for Aquaculture in Welsh Waters' described previously. The output modelled layers from this study have been appended with additional information from stakeholders and categorised. The aquaculture layers available in the Portal (see Figure 57) are a reduced suite of methods and species that omits finfish and crustacean farming. The layers describe the Resource Areas with the potential for cultivation of bivalves on the seabed, trestles or ropes, and on the potential for cultivation of macroalgae in medium exposure areas.

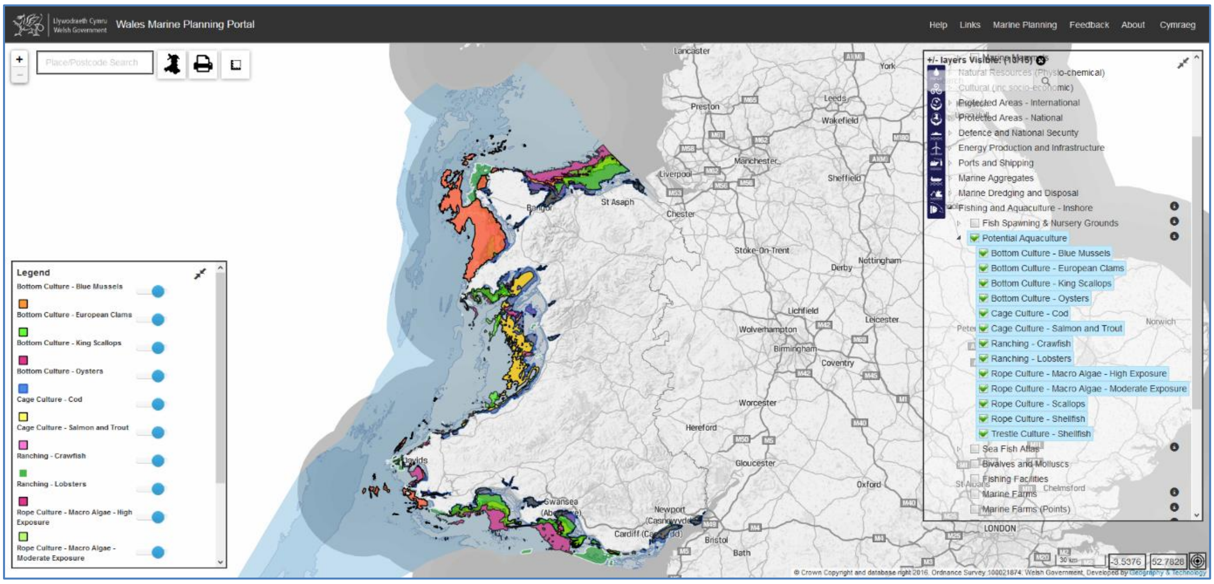

Figure 57. A screenshot of the Welsh Marine Planning Portal displaying the extent of areas considered to be suitable for a suite of aquaculture methods

Welsh Government have utilised the constraints areas identified in the APBmer study together with further information, to exclude areas from the Aquaculture Resource Area. Welsh Government considered the following to impose substantial constraints on aquaculture development and therefore such areas were excluded from the final Aquaculture SRA presented on the Portal:

- Tidal stream energy lease sites.
- Wave energy lease sites.
- Wind farm areas.
- Aggregates licenced areas.
- Aggregates exploitation areas.
- Hard structures such slipways, groynes, piers, etc.
- Cables.
- Pipelines.
- RSPB reserves.
- National Trust land.
- Dumping grounds – explosives.
- Dumping grounds (active) – dredge spoil.
- Most of the tidal stream energy Resource Area (Marine Plan).
- Areas of highly sensitive habitats (Maerl, *Modiolus modiolus*, seagrass, fragile sponge and anthozoan communities, *Musculus discors*, peat and clay exposures, carbonate reefs, oyster beds).
- Skomer Marine Conservation Zone.
- Suspended cultivation methods excluded from military practice area and firing ranges.
- Majority of Shipping SRA particularly approaches to ports. Some overlap with possible anchorage areas.
- Harbour areas.
- Existing Several Order areas.
- Offshore areas where seabed wave stress exceeds 0.6 nm^2.
- Area beyond 6 nm from shore.

Although busy shipping routes and channels represent a constraint on aquaculture development, some aquaculture operations may be compatible in these areas, including within port areas, although clearly this would require the approval of the port authority. Although the co-location of aquaculture in offshore wind farm sites is a popular concept and has been explored in a number of studies, e.g. Syvret *et al.* (Ref: 2015), co-location would require the resolution of operational risk associated barriers by both sectors. Welsh Government consider offshore wind farm sites to be a constraint on aquaculture development at present.

The result of applying the constraints to the original potential for aquaculture model layers is illustrated in Figures 58 and 59 overleaf. The original modelled areas for suspended rope culture of shellfish, mussels and scallops are extensive forming a near solid polygon from north to south Wales.

The application of the constraints layers removes a large proportion of this area from the final SRA presented on the Portal. Examination of SRAs for other sectors suggests that military practice areas, shipping, and offshore renewables account for the majority of constraints.

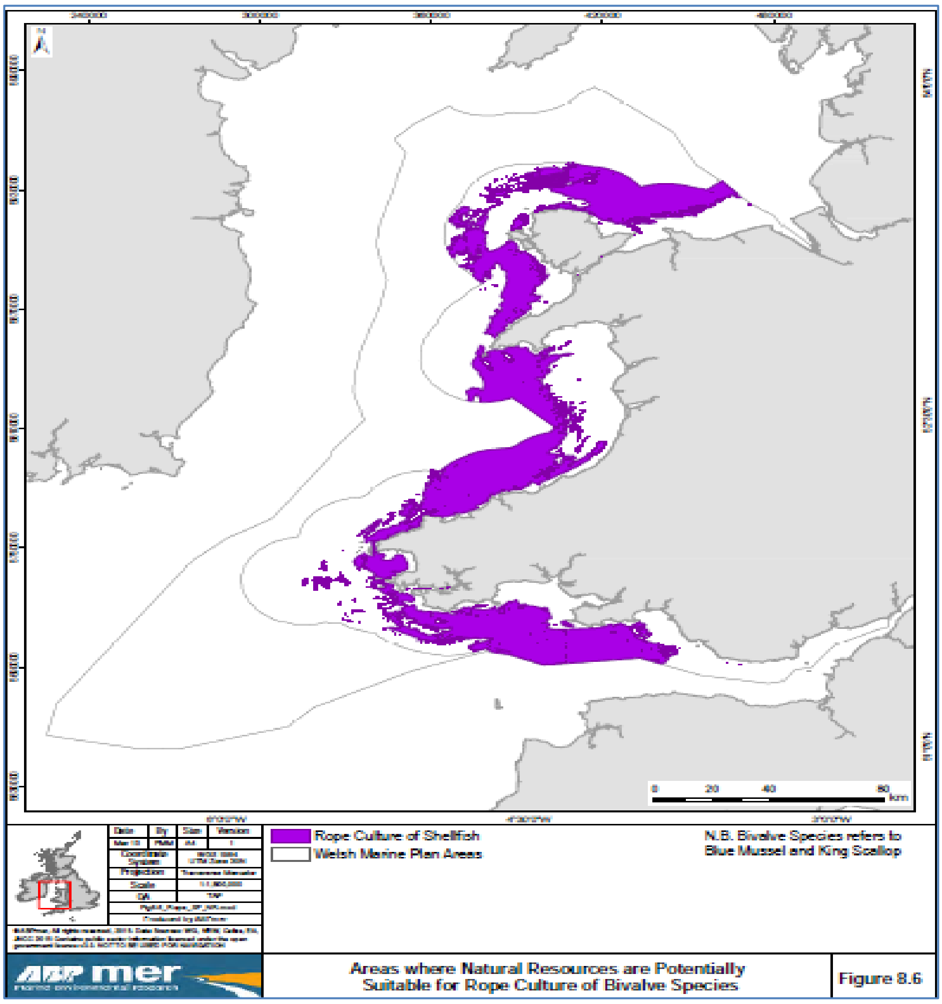

Figure 58. Welsh suspended shellfish aquaculture model spatial model for the Welsh Marine Plan Area (Source: ABPmer, 2015)

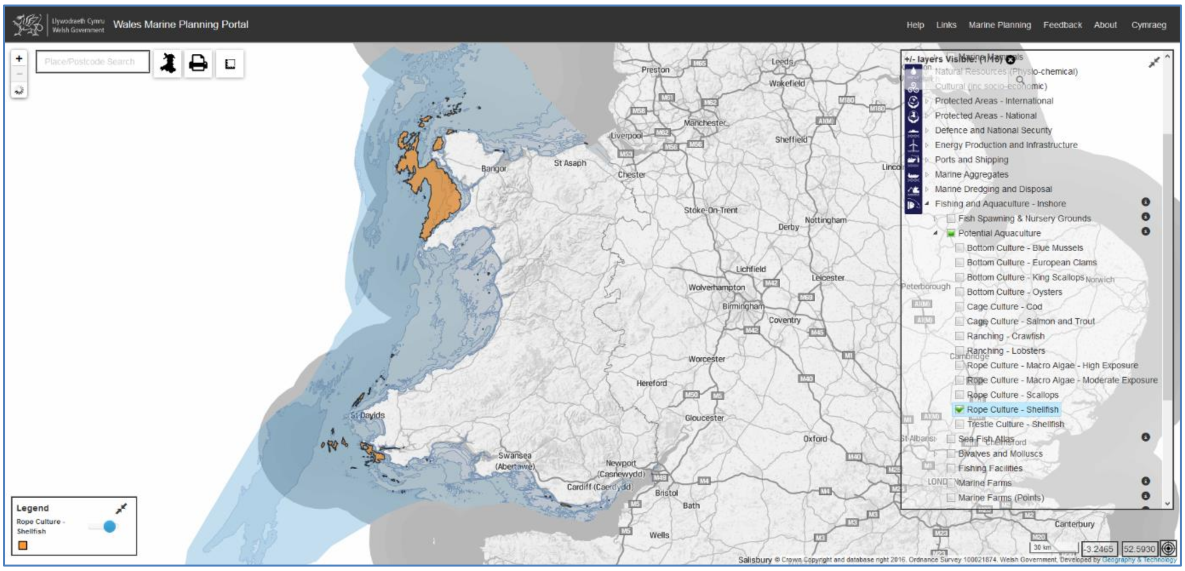

Figure 59. Strategic Resource Area for suspended shellfish culture after application of constraints

6.3 Site Level Spatial Planning Exercise

In the context of site level spatial planning, managers of tidal lagoons and port authorities developing Aquaculture Parks, and of course the aquaculture businesses themselves, require spatial analysis and data at a high resolution to inform the siting of operations.

Areas such as ports have a great number of other activities taking place in addition to the movement of shipping, which all present safety and operational constraints to developing aquaculture farms. Lagoons also have the potential for being multi-use sites and have their own operational and safety constraints that need to be understood.

As discussed in Section 9, the development of an Aquaculture Park may involve development of a streamlined site selection and consenting process through some form of pre-consenting by the developer and spatial analysis would help both the consenting process and subsequent management progress.

In order to explore the utility of this approach we attempted to carry out a spatial analysis for the potential of aquaculture in the TLSB site and the Milford Haven Port Authority's (MHPA) area of interest. Milford Haven Port Authority is currently formulating plans to develop aquaculture businesses within the Port and sites in the Pembrokeshire region. The Milford Haven Waterway is a busy site with extensive recreational activity and is a strategic energy port with oil and gas tankers regularly transiting the channel.

The model outputs from this analysis are based upon the Matrix and are regarded as representing the "area of search" for developers whilst forming a basis for managers to instigate fine scale local investigations of sites. These outputs, when combined with human-use information, such as recreational other commercial activities, can assist managers and developers in identifying key stakeholder groups for engagement and partnership development.

6.3.1 Approach and Method

The Scoping Matrix described in Section 2 provided the basis of our aquaculture model that underpins this analysis. The Matrix attempts to describe the operational envelope for each aquaculture métier describing the ecological range of the species defined by its tolerance to environmental variables e.g. temperature or salinity, and by the physio-operational requirements of the equipment employed, e.g. minimum water depth. In combination, these factors define where individual aquaculture métiers will be viable and where they could potentially be located within a site.

Spatial data for our study site was collated from publicly available sources including the European Marine Observation Data Network (http://www.emodnet.eu/), Natural Resources Wales Data Distribution Service, the Lle Geo-Portal for Wales spatial data distribution website http://lle.gov.wales/catalogue?lang=en&Text=&C=2007&Page=&INSPIRE=False, and data held by the Milford Haven Port Authority together with the authors own collated layers which were used to address data gaps in the publicly available data.

The ecological and operational range information collated in the Scoping Matrix was used to produce an SQL query in ArcGIS for each métier. These SQL queries represent a formal model describing the operational envelope for each métier, an example of which is shown in Figure 60.

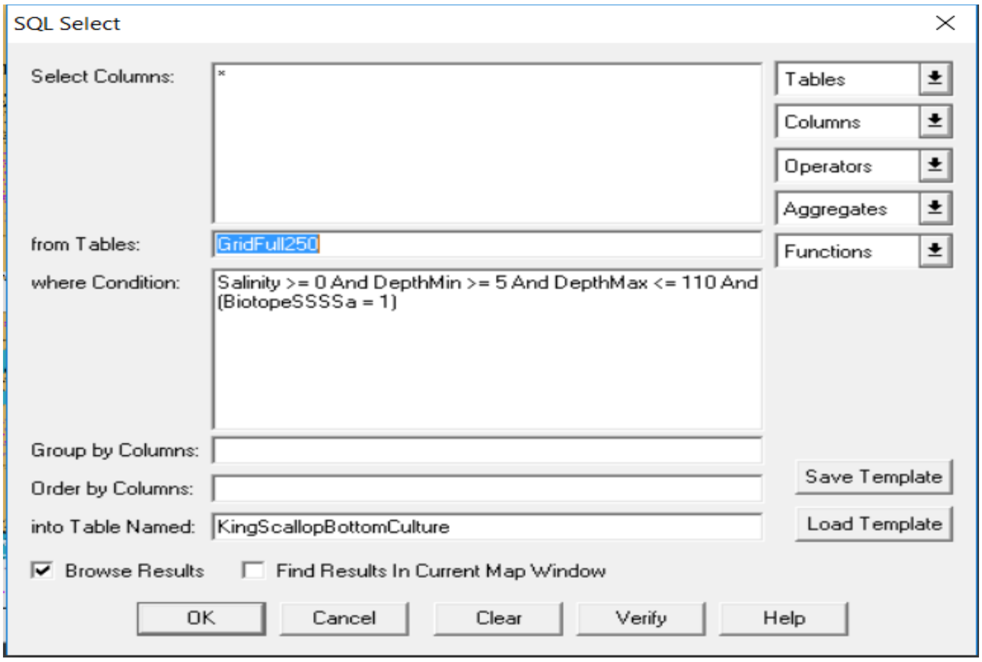

Figure 60. Example of SQL query used in analysis

6.3.2 Spatial Analysis Case Studies

6.3.2.1 Constraints to Site Level Spatial Analysis – TLSB

We initially intended to carry out our analysis for the TLSB using our Scoping Matrix (see Section 2) as a basis for the aquaculture model and then applying it to environmental layers of the post-build lagoon. However, discussions with TLSB highlighted a number of uncertainties about key environmental conditions that will be present in the post-build lagoon. Despite TLSB's efforts to generate spatial data describing the physical environment in the detail that was required for the analysis, we were unable to take this forward at this time. As the TLSB development moves forward, we expect the uncertainties to be addressed and the model can then be applied at a later date.

6.3.2.2 Milford Haven Port Authority Spatial Analysis

The Milford Haven Port Authority is currently developing plans to attract aquaculture businesses to the Waterway and the Pembrokeshire region. The case-study analysis carried out in the current study was intended to identify those areas of the Waterway where it may be feasible to site aquaculture métiers. This analysis represents a scoping exercise to direct developers and mangers to individual site level investigations.

Figure 61 overleaf, describes the areas of the Waterway where it may be feasible to site suspended rope mussel equipment. Mussels have a broad ecological tolerance to environmental variables such as salinity whilst suspended rope farming equipment is constrained within this site mainly by the maximum depth range. The depth range used in the Scoping Matrix was formulated with lagoon developments in mind and so some more shallow areas than would be expected are included.

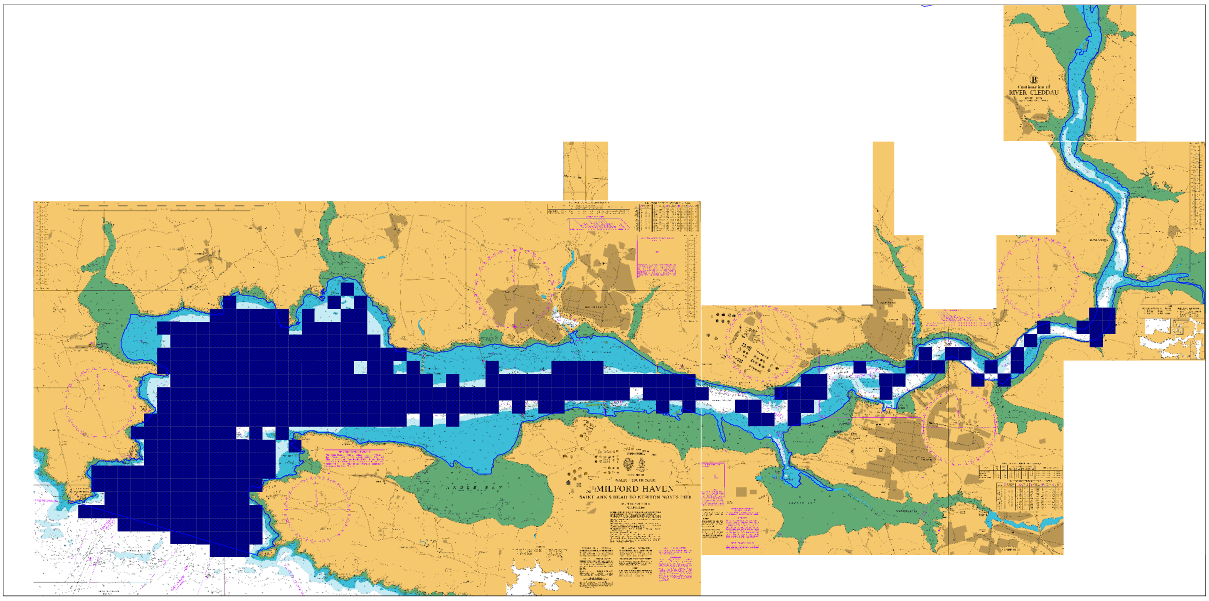

Figure 61. Modelled output showing where suspended rope mussel cultivation may be feasible in the Milford Haven Waterway

Figure 62 shows the areas of the Waterway where it may be feasible to site suspended rope seaweed (*Laminaria* spp.) farming equipment. The model output for seaweed farming is similar to that of the possible suspended mussel areas due to similarities of the equipment used, however the salinity tolerance of *Laminaria* constrains this potential activity further up the estuary where salinity is more variable.

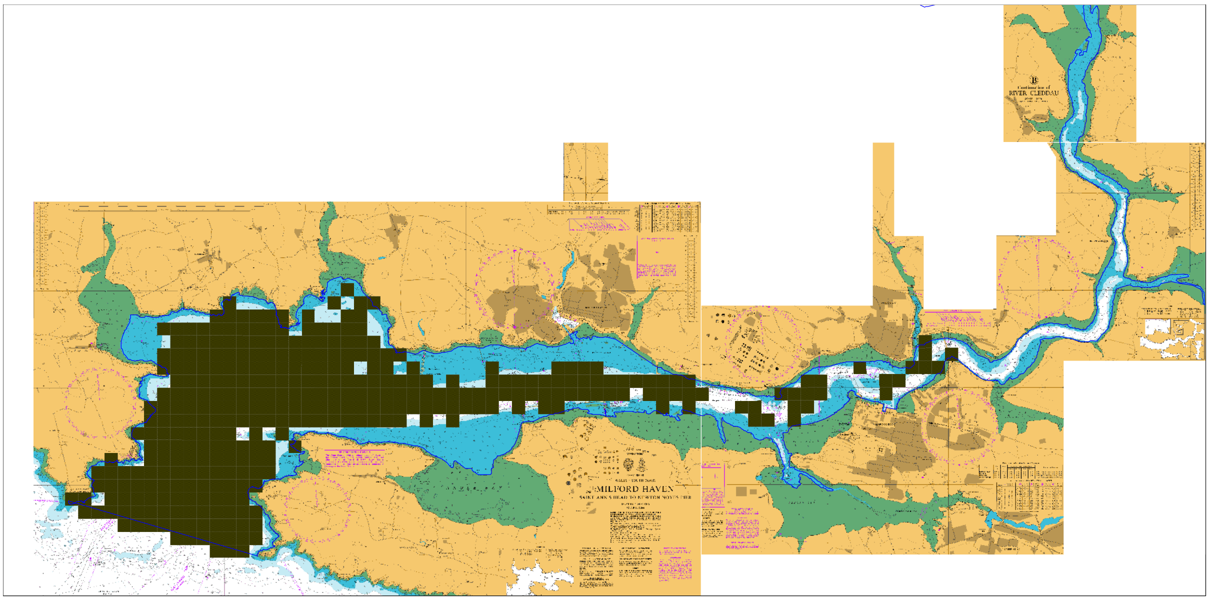

Figure 62. Modelled output showing where rope Laminaria farming may be feasible in the Milford Haven Waterway

Port areas such as the Milford Haven Waterway have a great number of other activities going on within them. Figure 63 demonstrates how the use of GIS tools can help identify areas where conflict may occur and thus be avoided. This map displays areas of commercial and recreational anchorages and moorings and overlays them on the model output for suspended seaweed farms. Clearly this port has many more activities not least the movement and berths of LNG and petroleum tankers, by adding these potential constraints, managers can readily identify the key areas for potential development.

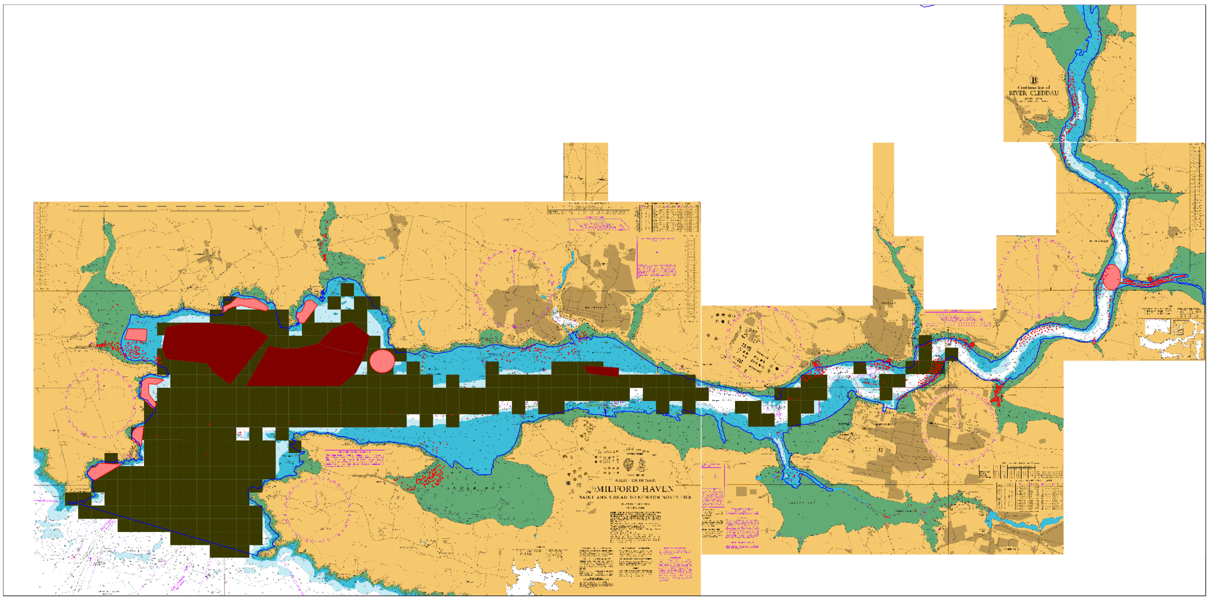

Figure 63. Locations of large vessel anchorages and recreational moorings overlaid on suspended seaweed potential areas

6.4 Discussion

Spatial planning tools are not intended to provide a definitive fixed point for managers or for prospective farm developers but should be viewed as decision support tools. The regional scale examples presented in Section 6 were produced for the purpose of marine plan production and are able to describe those large potential areas in which aquaculture development may take place over the life of the plan and beyond.

Analyses such as the regional level examples produced for the English and Welsh marine plan should be viewed with an eye on the future development of the industry. These analyses present areas, particularly offshore areas, which are not currently practical or commercially viable with current technologies. This does not preclude them from future development 10 to 20 years hence when offshore Aquaculture Parks may be economically and technically conceivable. The site level analysis carried out in this study has more immediate application as these areas are accessible and technically feasible with current technology and working practices.

Site level spatial planning offers much to managers, regulators and developers alike. However, implementation development of analyses and tools to support it faces a key constraint in terms of data availability, accessibility and gaps. Our analysis of the MHPA area of interest highlighted that spatial data on environmental variables may not exist and the raw point data from monitoring programmes may not be readily accessible. For fine scale analyses such data will simply not exist at all. We were able to use what data was available to us and identified where, on occasion, they may act as proxies for missing data. There is little the industry can do about the absence of environmental information other than to support initiatives to address data gaps and gather its own site specific information to support the consenting process.

Milford Haven Port Authority is developing an ambitious project with academic partners in the UK and Ireland aimed at addressing these data gaps and developing a range of spatial models that include economic analysis. The Aquacoast project's stated aim is to support sustainable aquaculture development in Ireland and Wales, mitigating risk and increasing the attractiveness to aquaculture and ancillary businesses. The project will undertake a level of consenting and environmental assessment to allow a Rochdale Envelope (Ref: Infrastructure Planning Commission, 2011) type approach. A series of work packages will define the opportunities for sustainable aquaculture development within these two areas and will include:

- Identifying sites, species and distribution carrying capacity.
- GIS mapping to assess site and species constraints and maximise commercial outputs by species.
- Research into environmental regulations and conservation needs.
- Research into biodiversity and other added benefits of the proposed aquaculture practise
- Potential yield analysis.
- Development frameworks.
- Trial methodologies.
- Definitions of success/commercial development procedures.

- Market assessment and development.
- Logistics and infrastructure development profiles.
- Development of models (viability and commercial) to enable full commercial development.

The web-based mapping tools developed for the Marine Plan projects in the UK's devolved administrations may offer an opportunity for further development of tools to assist aquaculture development. These are "live" sites and there may be opportunity to develop, at a site level, more detailed layers and use these sites as a planning tool at that level. Certainly, this may be an option for the development of regional Aquaculture Parks that may have support from development agencies. These web-based tools lend themselves to both site scoping for a range of prospective developers and as a point of reference for stakeholder engagement in sites that have many activities.

Such tools may not be necessary for sites such as TLSB as these are essentially a blank canvas for development. Spatial analyses for lagoons will focus more on identifying applicable areas for individual aquaculture métiers which can be implemented on the desktop.

SECTION 7 – PRODUCTION SCENARIOS AND COSTS

7.1 Introduction

Sections 7.2 to 7.5 are intended to give some general guidance on the likely production capacities of some of the main identified shellfish species and techniques. In addition, an estimation is also given of the likely capital costs of one identified unit of production. Section 7.6 gives a guide to likely costs of one long-line for macroalgal production.

The figures given are only intended to give a broad overview of likely costs of initial set-up. In reality, the cost of installing new systems will be site specific and very much dependent on the scale of the new operation as there are significant economies of scale that can be obtained with bulk purchases of many of the items of equipment required. By way of some examples;

- The cost of steel needed for trestles or staples for oyster cultivation is based on the total weight of metal purchased with lower prices quoted for orders over 1 tonne in weight.
- The primary cost of installing screw anchors is in the hire of the boat, crew and engineer with basic costs at around £2,250 plus incidentals. Screw anchors themselves are around £750 -£1,000 per anchor plus shipping. Offshore Shellfish Ltd. state that numbers of anchors that can be installed per day is between 2 and 22 depending on the weather with about 10 - 12 on an 'average' day.

The cost scenarios do not include or make allowance for the other costs that are independent of the production unit itself e.g. harvesting vessel, tractors, shore-side facilities and ancillary equipment etc. No allowance is also made for the cost of the seed required to produce the shellfish.

7.2 Production Scenario and Capital Costs – Intertidal Oyster Cultivation

We envisage that a successful commercial operation in the intertidal zone within the lagoon could be relatively modest at < 5 hectares. Pilot-scale trials would be needed in the first instance to determine system performance as well as oyster growth and mortality rates.

Although recent trials of native oyster cultivation in a high productivity area using the ORTAC cylinder system in the intertidal zone estimated that 1 hectare (10,000 ORTACs @ 6kg/ORTAC) could hold enough market sized stock (60 tonnes) to generate £600K at first sale (@£10/kg), it is suggested that a more conservative production scenario is adopted in the first instance. Our experience suggests that 1 hectare is likely to produce somewhere in the region of 40 to 50 tonnes of native oysters p.a. generating sales of around £400 – 500K annually. In terms of Pacific oysters, 40 to 50 tonnes p.a. could be expected to generate sales of around £160 – 200K annually.

It is important that there is a sufficient space allocation to grow successive year classes within the site based on a 3 to 4 year production cycle and for adequate spacing between rows for access. Depending on the outcomes of the pilot-scale trials we would also suggest that sea bed culture on the trestle site be considered as a way of increasing overall production from the available area. With Pacific oysters, production cycles would be reduced to approximately 2 years in productive waters but would have to be within containment.

The main costs of a 1 hectare unit of production for intertidally cultivated native oysters in this scenario would be the oyster growing cylinders and the steel trestles. The ORTAC cylinder has a cost of ~£5 - 6 per unit. The steel frames are approximately £12 each and each staple will hold 5 cylinders.

The Authors have estimated that a 1 hectare unit of production, allowing for vehicle access, could hold 950 steel staples, at a total cost of £11,400, plus 4,750 ORTACs, at a cost of £23,750. Total cost is therefore £35,150 for a 1 hectare unit of production that at 5 kg per ORTAC could hold 23,750 kg of finished product i.e. doesn't allow for other size classes. Total value at the price stated in Sections 8.2 and 8.3 would therefore be around £95,000 for Pacific oysters and £180,500 for native oysters.

7.3 Production Scenario and Capital Costs - Subtidal Oyster Cultivation

7.3.1 Seabed Cultivation

The benefit of seabed cultivation or ranching of oysters where a suitable substrate exists, is that it can occur in co-location with other waterborne activities as no structures are required. This might well therefore allow cultivation activities in areas of the proposed lagoon that are to be designated for other water users.

Estimates for the optimum stocking density of, for example, native oysters grown on the seabed do vary and will of course be site specific, dependent mainly on the levels of primary productivity. A conservative estimate for stocking density would be 10 native oysters per m^2 (the average density within the Mumbles Oysters Company's site). If productivity levels are higher then it is possible that 20 to 30 oysters per m^2 could be considered. Based on this range of stocking densities then 1 hectare could hold enough market size stock to generate between £70K to £210K at first sale (@£10/kg). Growth time to market would depend on the initial size of the re-laid oysters but in total would be around 3 years in a reasonably productive area. Using the same stocking density for Pacific oysters would give values of around £28K to £84K per hectare at first sale.

In this scenario, there are no capital costs of the actual 1 hectare unit of production as the oysters are laid directly onto the seabed. Whilst this return is less than intertidal culture using trestles, the resources required to produce the oysters are also considerably lower. The cost of harvesting will depend largely on whether the oysters are exposed at low tide, but in the likely scenario that they will be permanently submerged then some form of boat with dredges will be required. Alternatively, if the water is shallow enough then an eco-harvester may be suitable (see Figure 28).

Whilst it seems likely that suitable seabed habitats will exist within the lagoon, there is also a question of sedimentation which could be an issue. Pilot-scale studies would therefore be necessary to determine viability. Close coordination with the lagoon operators would be required to ensure that stock isn't placed in areas due for maintenance dredging within the production cycle.

7.3.2 Suspended Cultivation

It is possible that suspended culture approaches utilising floating cages (e.g. Microreef) or rafts could be employed within the proposed lagoon. The critical variable in deciding on what cultivation system could be used will be the residual depth of water at low tide and the difference in height between low and high water. These depths will determine how, for instance, buoyed headlines could be deployed. It is likely that cages or trays such as those shown in Figures 23 and 24 might be used or even the new Microreef systems shown in Figure 45.

Discussions with producers overseas suggest that a 1 hectare site containing 20 rafts/suspended tray systems have the potential to produce 100 - 180 tonnes per year (with a value of £1M to £1.8M). Scaled to accommodate successive year classes, 4 hectares of production area would ensure this level of output annually. However, growth rates and system performance are both highly site dependent and therefore pilot-scale trials would need to be carried out initially.

7.4 Production Scenario and Capital Costs – Intertidal Native Clam Cultivation

7.4.1 Intertidal Ranching

A 1 hectare site is likely to have around 4,000 m^2 of useable space when allowing for access around the 2 m wide areas of net where the clams are cultivated. Typical stocking densities for native clams sown into intertidal sediments range between 400 to 800 per m^2 determined by local primary productivity levels, with densities of 400 per m^2 being more likely. Based on a 50 % survival rate over 3 years' growth to market size then, at 20 g per clam, this gives a total production of market size product of between 16 tonnes to 32 tonnes per hectare.

At the market price of €29 (into European markets) shown in Section 8.6, then at this range of stocking densities, 1 hectare under cultivation could hold enough market size stock to generate between €464K to €1928K at first sale.

The main cost of equipment for a 1 hectare unit of production for clams under netting would be the netting itself. Prices in the UK for clam netting would be approximately £160 per 1,000 m^2. Netting would probably need to be replaced at least once over the growth cycle i.e. larger mesh size to allow increased water flow to the substrate as the clams grow. Mesh would be discarded after use.

7.5 Production Scenario and Capital Costs – Subtidal Mussel Cultivation

The major capital costs of installing a production unit of one long-line for suspended mussel cultivation are the anchor system, rope and floats. In this scenario, we would cost the screw anchors at £1,100 each installed i.e. £750 for the anchor and a pro-rata cost of £350 for installation (based on £4,000 per day boat hire plus incidentals for 10 anchor installations/day). Floats would be around £2,000 (based on 40 floats at £50/float). Rope costs etc. would be in the region of £1,200. Total cost of a single long-line would therefore be approximately £5,400. Lifespan of the equipment would be around 4 years for the long-line and 6 years for the floats.

Production at the proposed Swansea lagoon site would be determined by depth above chart datum i.e. to allow the rope mussel droppers to stay in suspension. A nominal 4 m depth is assumed in this respect although this would need to be confirmed. Therefore, a 200 m header rope with 1 m intervals between 4 m rope droppers would give ~800 m of rope under cultivation. Based on a conservative production figure of 5 kg per metre of dropper this gives a production of 4,000 kg per long-line. Using the quoted market price described in Section 8.4 this gives a gross production value of market size stock per long-line of £4,800. More mussels could be produced if a continuous loop system was used.

7.6 Production Scenario and Capital Costs – Subtidal Scallop Cultivation

As with the Pacific and native oysters there appears to be very little literature available concerning the economics, either actual or predicted, of offshore scallop culture. This is perhaps to be expected given the current low level of actual offshore production that takes place. The Seafish Economic Model contained as part of the Hyperbook series may be of some use in predicting the results of various production scenarios.

Of the literature available, Laing (Ref: 2002) states that for seabed cultivation based on seeding 75,000 scallops per year, with 15 % mortality and harvesting by diver collection, commencing after 3 years, the profit is 23 % of costs. However, Parsons and Robinson (Ref: 2011) state that there are several factors that make scallop aquaculture marginal at best at present in economic terms. These factors include the high cost of wild seed, when available, and the relatively long grow-out time, that they estimate as greater than 3 years from egg to a minimum marketable shell size of 10cm. The high capital and labour costs, especially of ear hanging, are stated as making seabed rather than suspended cultivation more attractive for aquaculture. Cano *et al.* (Ref: 2000) stated that Southern Spain was one of the only regions where grow-out time for suspended culture would be economic. They estimate that scallops can be on-grown to 10 cm in approximately 18 months in that region.

7.7 Capital and Operating Costs - Subtidal Cultivation of Macroalgae

The outputs of the Energetic Algae ('EnAlgae') project described the macroeconomics of suspended offshore rope culture of macroalgae. The costings in Euros of two types of long-line configuration are given in Table 1 as follows and are for indicative purposes only.

Table 1: Estimated cost (€) for one 100 m long-line and one 100 m long-line + V-droppers (Ref: Dijk, and Schoot, 2015)

	longline	Longline + V-droppers
Header rope	350	350
Anchor rope and chain	300	300
Anchor blocks	1,550[1]	1,550[1]
Buoys	400	400
Trawl floats, shackles and tying rope	165	165
Dropper rope		15
Tying string + cement droppers		25
Total	*2,765*	*2,805*
Navigation buoys, 4	*11,840[1]*	*11,840[1]*

1 Including deployment at sea

The cost of each type of long-line is therefore around £2,300. The figure of €11,840 is for a farm site with large offshore marker buoys which may not be needed in a lagoon environment where there is unlikely to be significant marine traffic. Lifespan of the equipment would be around 4 years for the long-line and 6 years for the floats.

Table 2 outlines the economic assessment of costs of an offshore macroalgae farm based on work by the EnAlgae Project (Ref: Dijk and Schoot, 2015). The scenario summarised in Table 2 is based upon an offshore farm with 100 linear long-lines and a total production of 100 tonnes of fresh seaweed biomass.

Table 2: Make-up of the cost price (€/kg FW) for a seaweed farm with 100 linear long-lines(Ref: Dijk and Schoot, 2015)

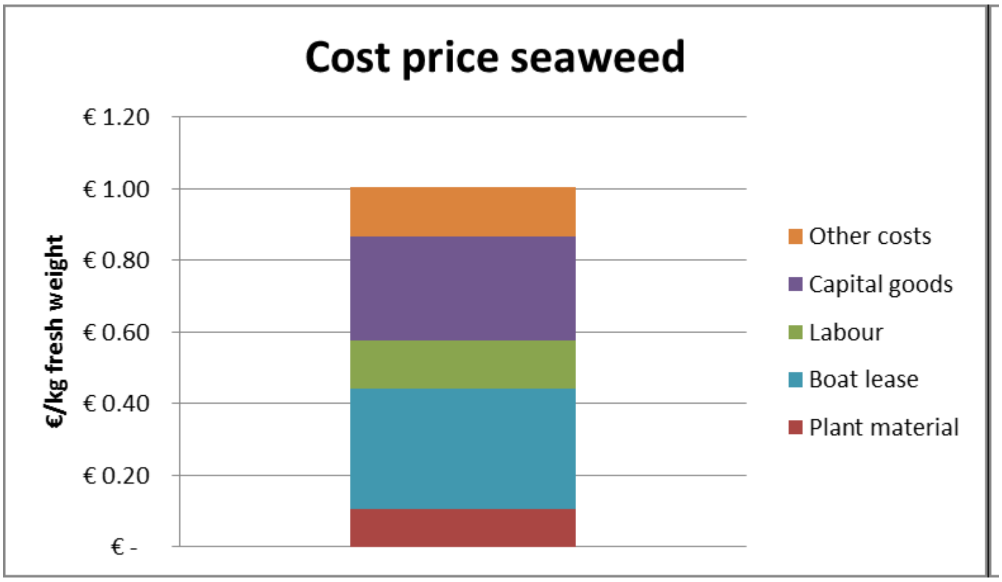

Table 2 shows a cost price of €1.00/kg fresh weight consisting of costs for plant material (10 %), capital goods (32 %), boat lease (33 %), labour (14 %) and other costs (11 %).

SECTION 8 – PRODUCTION LEVELS AND MARKETS

8.1 Introduction

Section 8 provides a brief overview of current UK production levels of shellfish species considered as being possible candidates for cultivation within the proposed tidal lagoon at Swansea.

Hambrey and Evans (Ref: 2016) state that the limited overall growth of aquaculture in EWNI contrasts starkly with the increase in aquaculture production seen in Scotland and other parts of the world where farming is now replacing capture. Shellfish production in EWNI is also stated as being in decline since 2010 (see Figure 64) and stagnant at best with a need for further initiatives in revitalise this sector.

	Finfish			*Shellfish*			*Total*		
Production (T)	2012	2013	2014	2012	2013	2014	2012	2013	2014
England	8,709	6,632	6,456	6,915	7,577	2,456	15,624	14,209	8,912
Wales	453	484	497	8,999	8,344	7,945	9,452	8,828	8,442
Northern Ireland *	600	605	750	4,920	3,463	3,238	5,520	4,068	3,988
Scotland	168,006	168,945	185,023	6,525	6,935	7,980	174,531	175,880	193,003
EWNI	9,762	7,721	7,703	20,834	19,384	13,639	30,596	27,105	21,342
UK	177,768	176,666	192,726	27,359	26,318	21,619	205,127	202,985	214,345
Imputed value (£m)	*Finfish*			*Shellfish*			*Total*		
England	21.53	16.66	23.73	10.06	17.19	5.17	31.59	33.85	28.90
Wales	1.44	1.63	2.13	9.01	15.86	15.10	10.45	17.49	17.22
Northern Ireland *	1	3	3	5.35	6.10	4.75	6.70	8.76	7.49
Scotland	532.95	690.83	733.64	8.77	8.95	10.55	541.72	699.78	744.18
EWNI	24.32	20.95	28.60	24.42	39.15	25.02	48.74	60.10	53.61
UK	557.27	711.78	762.23	33.19	48.10	35.57	590.46	759.88	797.80

Figure 64: Production and value of UK aquaculture 2012 to 2014 (Ref: Hambrey and Evans, 2016 based on figures supplied by Cefas)

Hambrey and Evans go on to say that whilst this demonstrates the economic potential of aquaculture, it also highlights the substantial competition already in place, and the challenging context for future expansion in the UK, especially in EWNI. Given this, the availability of new, high quality sites for aquaculture with the provision of associated services and the potential for a fast-track to commercial production levels (see Section 9), should be warmly welcomed.

Production figures and values for shellfish are based on the latest published aquaculture statistics available from Cefas which relate to 2012 (Ref: 2015) with updates as provided by Hambrey and Evans (Ref: 2016) based on further correspondence with Cefas as part of their excellent recent report for Seafish looking at the economic contribution and value of aquaculture in England, Wales and Northern Ireland (EWNI).

Cefas report shellfish cultivation production as being ‘On bottom’, which means seabed cultivation, and ‘Off bottom’ which will be suspended cultivation, e.g. rope-grown mussels, as well as bag/trestle cultivation. ‘On/off bottom’ describes production tonnages where both types of cultivation are practised i.e. there is no delineation provided.

8.2 Pacific Oysters

8.2.1 Farmed Production Levels and Values

Cefas state (Ref: 2015) that total farmed production for Pacific oysters in 2012 was 1,206.3 tonnes worth £4,911,600 making it the second most important shellfish species behind mussels under cultivation in the UK. Production in the UK is split as follows in Table 3:

Table 3: UK farmed production for Pacific oysters in 2012

Nation	Method	Tonnage	Estimated price per tonne	Imputed value
England	On bottom	850.0	£4,000	£3,400,000
Wales	On bottom	3.0	£4,000	£12,000
Scotland	Off bottom	216.00	£4,400	£950,400
Northern Ireland	On bottom	137.3	£4,000	£549,200

It is assumed in Table 3 that the English production figures include an element of both seabed and bag/trestle cultivation as these are both known to be practised in England. Welsh, Scottish and Northern Irish figures would most likely be bag/trestle cultivation.

Production is generally characterised by small farms with some larger scale seabed cultivation in areas such as Poole Harbour. Hambrey and Evans (Ref: 2016) state that the number of EWNI businesses involved in oyster farming, presumably both Pacific and native, is 36 with Direct Full Time Employment (FTE) of 184 and with a direct Value added figure of £2.3 million (assuming value added at 0.5 of first hand sales).

The relative levels of production between nations of the UK are presented in Figure 66.

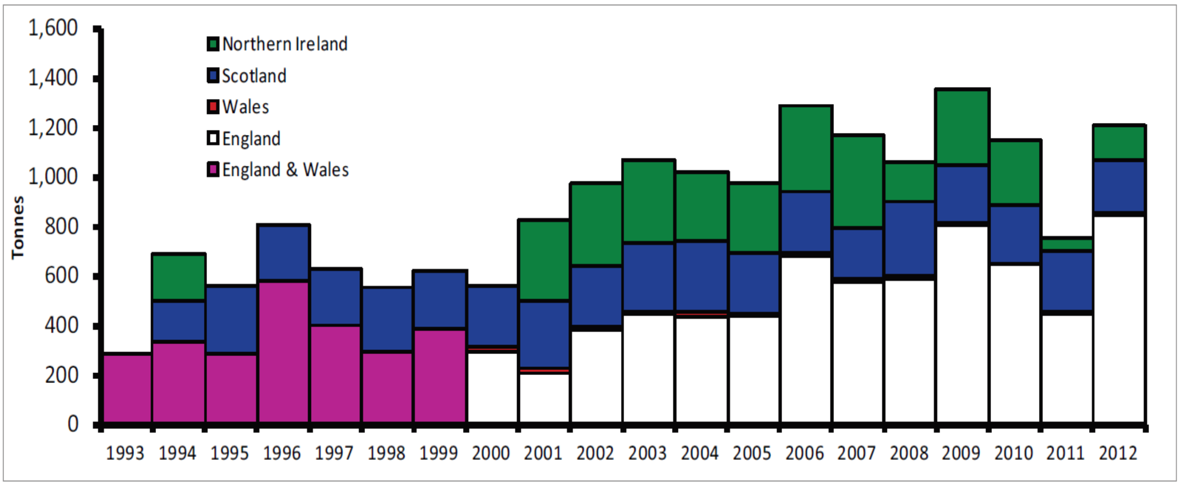

Figure 65: Time series of UK Pacific oyster production (tonnage), split by nation where reported (Ref: Cefas, 2015)

It should be noted that these production figures do not include the Channel Islands where approximately 900 tonnes of Pacific oysters are farmed each year.

8.2.2 Markets

In terms of the final market, oysters are usually sold live in-shell. A variety of processed and value-added products are being developed, either by growers or by their customers, e.g. flash frozen in the half-shell, although this is still very much in developmental stages. There is a small but dedicated market for oysters in the UK for which UK growers, up until recently, had been under pressure from imports from France and Ireland. This had led to a stabilisation or even a decrease in the selling price of the stock in many areas.

However, the occurrence of Oyster Herpes Virus (OsHV-1) in France and the massive stock losses that this has caused in the last few years has meant that there has been a shortage of supply into the European market. This has encouraged exports into France with a consequent increase in market prices that can be obtained for UK producers.

France is the primary market for production by Jersey growers with current exports estimated at around 950 tonnes per annum. Prices achieved by Jersey growers in the French market for undepurated product for the table market are stated to be €3.80 to €4.50 per kilo which equates to £3.22 to £3.80 per kilo at current exchange rates.

The losses through Oyster Herpes Virus (OsHV-1) have also resulted in a strong market demand for half-ware stock for on-growing by the French industry, a market that is currently being targeted by some growers in the South West of England. However, there are signs that breeding programmes within France may be starting to help tackle this disease issue and so long-term high French market prices and under-supply cannot be guaranteed (Ref: Syvret *et al*., 2013).

There is a growing overseas market for UK oysters with reported exports now taking place to the Far East and Asia. Hambrey and Evans (Ref: 2016) report that oyster production in southern England is now transported to the major seafood hubs in central Scotland for onward distribution to both the continent and East and South East Asia. Currently 67 % of UK oyster production is exported. Overall, the markets for both native and Pacific oysters are now considered to be strong with rising prices.

8.3 Native Oysters

8.3.1 Farmed Production Levels and Values

Cefas state (Ref: 2015) that total farmed production for native oysters in 2012 was 110.9 tonnes worth £843,106 which is split as follows in Table 4:

Table 4: UK farmed production for native oysters in 2012

Nation	Method	Tonnage	Estimated price per tonne	Imputed value
England	On bottom	85.9	£7,600	£653,106
Wales	-	-	-	-
Scotland	Off bottom	25.0	£7,600	£190,000
Northern Ireland	-	-	-	-

In Table 4, English production most likely relates to seabed cultivation and Scottish production to bag/trestle cultivation.

To give some insight into possible production values that might be associated with subtidal seabed cultivation of native oysters, at a low to medium density of 20 oysters per m^2, this would give a total number of oysters per hectare of 200,000. Using a recent market value of €6.50 per kg (~65 cents/oyster) for undepurated stock being sold into France, this would give a total value per hectare of cultivated seabed of €130,000 or £95,000. By comparison, prices for depurated native oysters sold direct to top end restaurants in the UK are likely to be in the region of £8.00 to £10.00 per kg (when allowing £100/tonne for depuration costs). Using the scenario described above this would give a value of £160,000 to £200,000 per hectare excluding packaging costs and transport to market (packaging costs would be about £6 per 25 kg polystyrene box, £1 per 13 kg wooden French basket and £0.70 per 5 kg small wooden basket in Ref: Syvret and Woolmer, 2015).

8.3.2 Market

The market for the native oyster is predominantly based around being sold live in-shell. Typically, for smaller orders, oysters are supplied chilled in waxed, waterproof cardboard boxes or in wooden punnets. Potential options for selling oysters include direct sales to the public either at the 'farm-gate' or through mail order, with web-based ordering now popular for the supply of small quantities of oysters.

Other local markets might include fishmongers, farmers' markets or restaurants, potentially with delivery direct to the customer. Larger quantities of oysters might be supplied to wholesalers either depurated or undepurated with a consequent price differential. Bulk sales of British oysters do take place into the European market with France stated as a primary market in this respect.

Age at harvest with seabed cultivation is likely to be around 30 to 36 months with a harvest size of between 60 to 100 g per oyster. The native oyster is often regarded to be a 'premium' product when compared to the more widely available Pacific oyster and this is reflected in prices charged at the table with, for example, London restaurant prices quoted as £24 to £28 per half dozen for native oysters versus £14 to £18 per half dozen for 'Rocks'. The FAO aquaculture guide states that in Europe the wholesale average price is commonly 3 to 5 times greater for native oysters compared to Pacific oysters.

One drawback with the native oyster is that during its reproductive phase developing young oysters are retained within the oyster's mantle cavity for a few weeks. The practical consequence of this is that native oysters can only be consumed from September to April (months with an 'r' in them) when they are not brooding these young oysters. This is not the case with Pacific oysters which do not retain the developing larvae, although they will also be subject to a loss of condition following spawning that may render them unmarketable for a period of time.

Production figures indicate that in 2012 approximately 111 tonnes of native oysters were cultivated in England and Scotland with no Welsh production (Ref: Cefas, 2015). This is a small production level when compared to France and Spain which produced 2,683 tonnes in 2010 (Source: Eurostat). The dramatic reduction in French Pacific oyster production in recent years due to Oyster Herpes Virus (OsHV-1) means that there are market opportunities at present for oyster exports to the Continent.

Whilst the market for native oysters is smaller than that of Pacific oysters there is a place for premium high-value "genuine native" production. Overall, the markets for both native and Pacific oysters are now considered to be strong with rising prices (Ref: Hambrey and Evans, 2016).

8.4 Mussels

8.4.1 Farmed Production Levels and Values

Cefas state (Ref: 2015) that total farmed production for mussels in 2012 was 26,021.3 tonnes worth £27,292,020 making this the most important shellfish species for aquaculture production in the UK. Production in the UK is split as follows in Table 5:

Table 5: UK farmed production for mussels in 2012

Nation	Method	Tonnage	Estimated price per tonne	Imputed value
England	On/Off bottom	5,965.7	£1,000	£5,965,700
Wales	On/Off bottom	8,996.0	£1,000	£8,996,000
Scotland	Off bottom	6,277.0	£1,200	£7,532,400
Northern Ireland	Off bottom	76.6	£1,200	£91,920

In Table 5, English production is shown as being predominantly based around seabed cultivation whereas Scottish production is dominated by rope-grown mussels. This situation may change in the next few years with a likely increase in English rope-grown mussel production due to the expansion of offshore shellfish farming being driven by Offshore Shellfish Ltd. The Welsh production is almost entirely based around cultivation on the seabed, particularly in the Menai Straits, with some rope-grown production in Swansea Docks.

The relative levels of production between nations of the UK is presented in Figure 67.

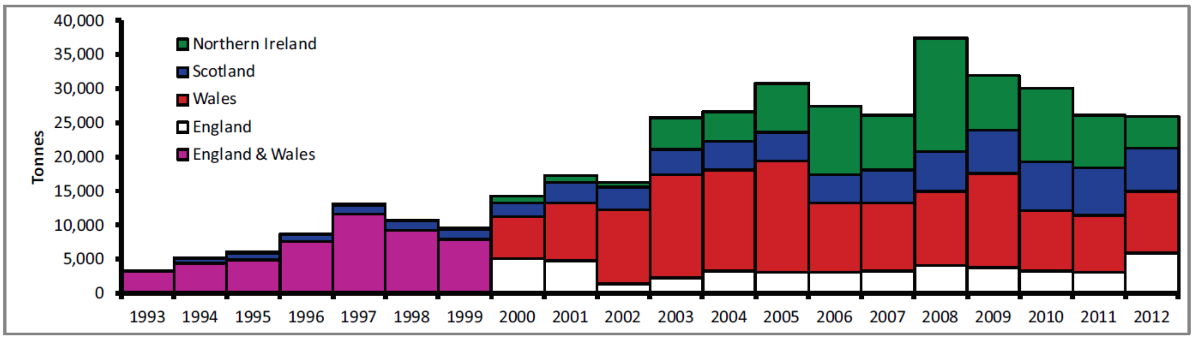

Figure 66: Time series of UK mussel production (tonnage), split by nation where reported. (Ref: Cefas, 2015)

Mussels are by far the most important shellfish species in terms of UK aquaculture production with about 95% of the total shellfish tonnage in 2012, and at about £9 million harvest sale, some 80% of the total income (Ref: Hambrey and Evans, 2016). Hambrey and Evans (Ref: 2016) state that the number of EWNI businesses involved in mussel farming is 25 with Direct Full Time Employment (FTE) of 125 and with a direct Value added figure of £6 to 12 million (assuming value added at 0.5 of first hand sales). By way of an example of their value to both the local and national economy, an article in The Herald (Scotland) stated that in 2012 Shetland alone produced 4,340 tonnes of rope-grown mussels generating £5 million for the local economy and employing over 130 people.

8.4.2 Markets

Seafish state that rope-grown blue mussels take approximately 2 years to reach marketable size (45 mm shell length or above) although this is dependent on the location and productivity of the cultivation site and the destination market (Source: Suspended Mussel Hyperbook). Sources of mussel supply to the market will vary seasonally depending on when mussels are spawning and therefore not fit for sale due to low meat yields.

Much of the current mussel production from the North Wales seabed cultivation sector is exported straight to Holland. Other markets for UK mussels include France, Spain and other European markets. It has been stated that as home consumption of mussels increases then depuration and sale of product to UK consumers will become a viable proposition for Menai Straits' producers (James Wilson, pers. comm.). In comparison, a significant proportion of Scottish produced mussels undergo processing and are sold as a vacuum packed high-end, luxury convenience food.

This is a growing market for mussels both in the UK and overseas with rising domestic popularity of mussels, falling Spanish production and a European market that demands considerable volumes of product. As such, there is the potential to supply mussels for the bulk market, high-value sales as well as the convenience food sector of the market. However, given the significant global competition it is likely that the best chance of success in growing this sector lies in developing large-scale levels of production (Ref: Hambrey and Evans, 2016).

8.5 Scallops

8.5.1 Farmed Production Levels

There is only very limited European aquaculture production of scallops. Spain was the major supplier of farmed scallops but this industry has now collapsed. Current aquaculture production of scallops is therefore limited to Ireland and Norway with a small level of production in the UK and France (Ref: Hambrey and Evans, 2016). Cefas state (Ref: Cefas, 2015) that total farmed production for scallops in 2012 was 7 tonnes which is a decrease on 2011 when 10 tonnes of production was reported. Production through aquaculture only took place in Scotland and is thought to be centred around one company called Scot-Hatch which was set up in 2010.

Scot-Hatch on-grow seed scallops in trays and lantern nets until such time as they are big enough to ranch on the seabed. Scot-Hatch have previously been reliant on seed imports from Scalpro in Norway but are thought to be seeking funding to develop their own hatchery, in collaboration with Scalpro, to produce scallop seed. The colder Scottish waters mean that it takes 4 to 5 years to produce a 125 to 140 mm scallop (Ref: Holmyard, 2015). Warmer southern waters would decrease grow-out time considerably with 3 years to market size thought to be achievable in productive waters.

8.5.2 Markets

Scallops are marketed either in-shell (usually alive) or as shucked meats (shell removed). The traditional European market is for roe-on meats (adductor muscle plus roe) (Source: Seafish Responsible Sourcing Guide). There is a strong market demand for king scallops with the price normally dictated by shell size and meat quality. Aquaculture derived scallops generally have an advantage in this respect as the product is likely to be of high quality, fresh or live and will have continuity of supply. Aquaculture production of scallops is also seen as being environmentally friendly when compared to wild dredge fisheries and as such these scallops can command a premium price. Hambrey and Evans (Ref; 2016) report that although production levels are low, prices for aquaculture produced scallops are currently high at around £10 per kilo. In terms of wild capture fisheries, the scallop is the most valuable shellfish capture species worth an estimated £65.4 million in 2015 (65,400 tonnes).

When cultivated, king scallops are generally considered ready for market when larger than 120 mm shell length (at approximately 250 g live weight, giving a meat yield of 55 to 60 g). The time taken to reach this size varies depending on location e.g. 3 to 4 years from spat collection in the south of England vs. up to 4 to 5 years in Scotland. When divers harvest king scallops off the seabed, they can select just those that are large enough to sell. Diver-caught scallops are a premium product and can generally be sold for a higher price than scallops dredged from a commercial fishery (Source: Seafish Hyperbook).

8.6 Native Clams

8.6.1 Farmed Production Levels

Globally, there is a large market for clams. Italy has been the biggest producer of clams (40,000+ tonnes) but production has suffered more recently due to disease issues (Ref: Hambrey and Evans, 2016). Cultivation in 2012 of non-native clam species, including the Northern quahog (Hard clam) and Japanese carpet shell (Manila clam), was 13.6 tonnes worth £42,076. Production was only recorded in England.

There is obviously a significant market demand for clams, and in particular for native clams. However, despite this, Cefas report (Ref: 2015) that there is currently no cultivation of native clams in the UK.

8.6.2 Markets

In terms of markets, although there are outlets for clams in the UK, much of the production is exported to the continent particularly France, Spain and Italy. In order to get an overview of prices in mainland Europe the main market prices were analysed. Mercamadrid in Spain for example confirmed average prices per kilogram for native clams (Clam Finas) were €32/kg as at December 2016 with a traded tonnage over 1 week of 1,050 kg (27/11 to 03/12/16).

8.7 Cockles

8.7.1 Wild Fishery Production Levels

Almost all cockle production is from managed fisheries under three Regulating Orders (Burry Inlet, Thames and Dee Estuaries) and two hybrid Orders (Wash and Poole Harbour). In England in 2011, 9,154 tonnes of cockles were produced from the Regulating Orders and 1,450 tonnes from the Hybrid Orders. Total value for English cockle production was £9,688,398. In Wales in 2011, 508 tonnes were produced worth £213,360 (Source: Shellfish News 35 Spring/Summer 2013). Cockle production figures have decreased dramatically in Wales in recent years due to unexplained mass mortalities.

Opportunities however do exist to harvest small cockles from very dense beds and then re-lay them at lower densities. Harvesting can then be carried out using techniques such as suction dredging. This type of managed fishery or ranching of cockles has attracted commercial interest (Ref: Hambrey and Evans, 2016).

8.8 Macroalgae / Seaweeds

8.8.1 Farmed Production Levels

It is estimated that worldwide in 2014, aquatic plant production, primarily seaweeds, stood at 27.3 million tonnes and was valued at US$5.6 billion of which the main value is related to products destined for human consumption (Source: FAO Yearbook). The latest FAO Aquaculture and Fisheries Production Statistics (Source: 2014) do not record any farmed aquatic plant production for the UK as at 2014 (as an individual country). By comparison, in 2014, Ireland produced 100 tonnes of aquatic plants (value US$133K), France 300 tonnes (value US$179K) and Denmark 100 tonnes (value US$ 64K). More recently there have been moves to try and develop cultivation of macroalgae in the UK, with Scotland leading the way through the newly formed Scottish Seaweed Industry Association (SSIA).

8.8.2 Markets

High value seaweed products; In the UK, there is a market and good potential for macroalgae as an artisanal food product. Indeed, Fish Farmer Magazine (Source: December 2016) reports that seaweed is "*one of 2016's biggest 'foodie' trends, being featured on restaurant menus in London and beyond*". In Wales, *Porphyra*, more commonly known as Laver is commercially collected and is used to make laverbread. The value of this industry is small and difficult to quantify but there are known to be a number of local family run businesses producing fresh laverbread direct for sale and at least one South Wales business (Parsons Pickles) producing tinned products at scale. Value to the Welsh economy has been estimated to be in the tens of thousands of pounds and volumes harvested in the tens of tonnes per year (Ref: Powell, 2011).

An example in Wales of alternative uses of *Porphyra* would be Selwyn's Seaweed Snacks which are produced from imported product. Examples of other edible seaweed species include *Undaria* (for food 'wakame' in Japan) and *Gracilaria* (for food and agar production in Ref: Syvret *et al*., 2013).

In summary, it would seem as though there is an opportunity through aquaculture to supply the market for food species macroalgae such as *Porphyra*. There may also be a market for macroalgae for inclusion in cosmetics, pharmaceuticals etc. or for use in therapy centres, seaweed baths etc. (Dr. Adam Powell, pers. comm.).

Seaweed as a bulk commodity; There is certainly a market for macroalgae as a commodity product, i.e. high volume, low value. Uses in this respect include as a constituent in animal feeds, plant supplements etc. As an example of possible prices, kelp has been stated to be worth €16 to €19/kg for bulk dry quantities (Dr. Adam Powell, pers. comm.). This would roughly equate to €1.6 to €1.9/kg wet weight.

Seaweed for energy generation: BioMara (the Sustainable Fuels from Marine Biomass project www.biomara.org) was a joint UK and Irish project that ran from 2009 to 2012. Its aim was to demonstrate the feasibility and viability of producing third generation biofuels from marine biomass. In economic terms, BioMara has reported that, as a standalone commercial venture, using seaweed for energy generation is marginal at current energy prices although it may offer other significant social and economic benefits (Source: http://www.biomara.org/news/summer-2012-newsletter-published). Lewis *et al*. (Ref: 2011) also reported that fermentation of seaweed to ethanol is not currently an economic process and that anaerobic digestion based on plants fed only with seaweeds does not look favourable on either a small or large-scale. They estimated that the cost of seaweed necessary to allow an economically viable anaerobic digestion process would need to be of the order of £100 to £300 per dry tonne delivered.

A project entitled EnAlgae has recently reported on the macro-economics of algae products (www.enalgae.eu Ref: Vort *et al*., 2015). They concluded that the outlook for biofuels derived from algae was promising but the biggest hurdle still remains producing algae biofuels at a competitive price. They also report that there is not the production capacity at present for large-scale manufacture of biofuels. In terms of electricity and heat generation, Vort *et al*. (Ref: 2015) concluded that the price of energy products based on algae biomass is still too high to be competitive in the energy market given the low price levels of fossil fuels.

There are now a number of schemes elsewhere in the world where both seaweed culture and shellfish culture are used to mitigate nutrient loads to the marine environment (Ref: Rose *et al.*, 2014) using a system of N credits but the Authors are not aware of any similar schemes in the UK. Nutrient scrubbing has however been trialled as a potential means of cleaning up effluent water from aquaculture production systems (Refs: Schlarb-Ridley and Parker, 2013; Syvret *et al*., 2013). For a review see the Project entitled 'Increasing Industrial Resource Efficiency in European Mariculture' (IDREEM - http://www.idreem.eu/cms/about-project/).

Summary; The cultivation of macroalgae in the UK as a bulk commodity is not yet at a level where it can meet the requirements of those markets. Details concerning potential market values of large-scale macroalgae production are still considered to be commercially sensitive (Dr. Adam Hughes, SAMS pers. comm.). It would appear that at present the use of algae biomass for fuel, electricity and heat generation is not economic given current fossil fuel prices.

For the short term at least, macroalgal cultivation within renewable energy sites such as lagoons, should probably be targeted at those species that can be used to supply the market for high-value products such as that for food, if hygiene conditions allow. Longer term there may be an opportunity to cultivate macroalgae as a bulk commodity as experience is gained in cultivation and processing techniques and economies of scale of production help improve profitability.

SECTION 9 – 'AQUACULTURE PARKS' A POTENTIAL BLUEPRINT FOR MARICULTURE IN TIDAL LAGOONS

9.1 Co-location of Aquaculture and Marine Renewable Energy

Co-location, or placing several entities or operations in a single location, for efficiency and mutual advantage is an idea that is increasingly being deployed in business anywhere there is a node of intersection of resource or specialist activity, e.g. data-sourcing, transport interchange systems, inland ports (Syvret *et al.*, 2013).

Within the current project, we are investigating the potential co-location mariculture opportunities that might be afforded by the proposed development of a tidal lagoon for renewable energy production within Swansea Bay. The possible development of a disease-free shellfish hatchery on the landward works of the lagoon also offers the prospect of cultivating marine organisms throughout their life cycle within the boundaries of the lagoon, although there are also opportunities for the use of natural seed supplies associated with such species as the native mussel (*Mytilus edulis*).

The scale of the lagoon and the requirement for spatial use by other marine users would suggest that the primary driver behind mariculture opportunities will be the production of high quality live seafood with the expectation of achieving premium prices through the use of existing local brands such as that of the Mumbles Oyster Company Ltd. Added to this, there is also the possibility of producing macroalgae, such as *Porphyra*, for direct consumption or as an ingredient in value added food snacks. It is thought unlikely that the area available for mariculture, as well as the current economics of production, will allow other mariculture activities such as macroalgae cultivation for non-food purposes such as bio-fuel production.

Underpinning the development of mariculture activities within the proposed tidal lagoon will be the 'restoration aquaculture' approach whereby the economic production of a food product also has wider ecosystem benefits such as that offered by reintroducing large numbers of disease free, biosecure, diploid native oysters back within the Swansea Bay area.

The associated policy drivers of interest in undertaking exploration into the opportunities associated with co-location relate to the efficient use of marine space, and to the UK food security and aquaculture policy.

Issues recognised by Defra that amount to a strong case for developing and increasing aquaculture, particularly offshore include:

- Food security
- Population health
- Improved environmental sustainability, and
- Increased socio-economic activity

The development of co-location activities in terms of aquaculture and marine renewable energy production may help towards achieving a balance between conservation and development and exploitation of our marine resources. The designation of more than 35 % of Welsh marine territorial areas (out to 12nm) as Marine Protected Areas means that there is increasingly a need to look at co-location, either in terms of co-location of commercial and restricted operations together, outside designated sites, or the co-location of appropriate operations within designated sites, with appropriate controls and balances in place (Syvret *et al.*, 2013).

9.2 Benefits and Perceived Drawbacks of Co-location

There are many potential advantages offered to Food Business Operators (FBOs) through mariculture activities within tidal lagoons.

In the case of the proposed Swansea Bay lagoon development these advantages to FBOs could include the following:

- Freedom from disturbance or damage by shipping as marine traffic will be excluded or controlled within the tidal lagoon.
- Modelling of the Swansea Bay lagoon with the proposed 1.5 km waste water outfall extension in place would indicate that water quality in terms of shellfish hygiene (modelled using *E. coli*) would be greatly improved within the tidal lagoon. A storm event simulation indicates upper *E. coli* limits of around 250 - 500 EC/100ml vs. predicted baseline levels, without the lagoon and extension of the outfall, of 2,000 - 10,000 EC/100ml.
- Economies of scale, possibility of increasing use of mechanisation.

In the case of Swansea Bay, advantages to TLSB as the developers could include the following:

- A demonstrated social good and Corporate Social Responsibility (CSR).
- Shared monitoring of environmental and ecological variables.
- Building and improvement of relations with existing marine stakeholders such as fishing communities and their associated lobbies.

However, despite what may seem some mutual advantages to FBOs and marine renewable energy developers there has to date been very few actual examples of commercial co-location carried out between these sectors, with the majority of co-location activities limited to pilot-scale or research projects.

Examples of perceived or actual risks identified by the offshore marine renewable sector in co-locating with aquaculture operations include the following:

- Possible impact or damage to energy generation assets, such as the turbines, due to lost or damaged aquaculture production equipment e.g. displaced long-lines.
- Interference with day to day or emergency maintenance and repair activities due to other vessel movements or placement of aquaculture equipment.
- Placement of aquaculture production equipment over areas that will periodically require maintenance dredging thus excluding dredgers.
- Loss of control over levels of health and safety exercised by other co-location activities within the spatial footprint of the tidal lagoon.
- Concerns over types and levels of insurance put in place by other commercial operators within the lagoon.

9.3 Marine Licensing of Mariculture Activities in Welsh Waters

The licensing of marine aquaculture in English and Welsh waters is generally defined in terms of distance from shore. For instance, where seabed is owned by the Crown, then The Crown Estate (TCE) is responsible for granting aquaculture leases for deployment of aquaculture equipment on the seabed (e.g. fixed gear such as in rope-mussel cultivation) out to 12 nm. There are certain areas of the seabed where the fishery may not be owned by TCE (e.g. Free Fishery of Severn Estuary) and the legal ownership will need to be ascertained for each lagoon.

Licensing to undertake seabed cultivation where some rights of ownership or tenure accrue to the aquaculture operator are normally granted through a type of Fishery Order known as a Several Order under the Sea Fisheries (Shellfish) Act 1967 and these cover areas out to 6 nm. Seafish has recently published a new report into the past, present and possible future contributions of Several and Regulating Orders and their role in UK shellfish production (Ref: Whiteley, 2016).

The situation is likely to be more complicated however when a lease has been granted to a marine renewable energy developer and operator. The granting of a lease for an offshore marine renewable energy development by TCE in the past has generally granted rights to the developer/operator for the whole area for the sole purpose of producing electricity.

However, whilst not excluding public right to navigation, fishing or where there is a grant of a “several fishery”, this lease does appear to exclude TCE from issuing a further lease within the marine renewable development area for any mariculture activities involving fixed gear. This was also the general conclusion reached in the questionnaire survey undertaken with wind farm operators by Mee and Kavalam (Ref: 2006) and then confirmed at their subsequent stakeholder meeting (see project report for transcript of questionnaire responses). In their SWOT analysis of aquaculture in offshore wind farms, the absence of a TCE policy for other economic activities within offshore wind farms was stated as a Threat that would act as a disincentive to investment in this respect. Mee and Kavalam go on to state that the development of offshore wind farms will lead to conflict with other profitable users and that the only way to avoid this is to develop joint consents for multiple uses co-existing with each other.

A similar situation occurs with Several Orders whereby rights of ownership accrue to the aquaculture operator. Syvret *et al.* (2013) state that there appears to be uncertainty as to whether a Fishery Order could be granted for an area within an offshore marine renewable energy site. If it were possible to apply for a Fishery Order in this way, then it was stated as being doubtful that an application by a third party would be successful without the agreement of the marine renewable energy operator as the existing leaseholder.

A summary of the marine licensing for marine aquaculture in English and Welsh waters is presented in Table 6 overleaf. Shading has been included to ease differentiation between licence types etc.

Table 6: Marine Aquaculture Licensing/Permissions

- Who has control of and issues aquaculture licences, and can offer legal protection for shellfish stocks, in Welsh waters for areas out to 12nm, for open waters and areas within offshore wind farms, for fixed gear aquaculture (e.g. rope-mussel culture) and 'ranching' (e.g. seabed cultivation of mussels)? (***Source: Adapted from Syvret et al., 2013***).

Control & Issue of Aquaculture Licences by License Type		**To 12nm for Fixed Gear Aquaculture**	**To 12nm for Seabed Cultivation ('ranching')**
Open Waters	**License Type**	**Crown Estate Lease**	TCE do not cover leases for 'ranching' (relaying/dredging shellfish). Public Right to Fish as seabed lease confers no rights to shellfish
	Control / Issuer	The Crown Estate	N/A
	Licence fee payable to	The Crown Estate: No application fee; annual rent reviewed every 5 years	N/A
Open Waters	**License Type**	**Marine Licence** from NRW for deposition of equipment where not exempt (e.g. hazard to navigation) – MCAA 2009 – otherwise Notification of an exempt activity form still required.	N/A
	Control / Issuer	NRW	N/A
	Licence fee payable to	NRW in Wales or MMO in England	N/A
Open Waters	**License Type**	N/A	**Fishery Orders (Regulating & Several)** - Sea Fisheries (Shellfish) Act 1967 - to 6nm
	Control / Issuer	N/A	Welsh Ministers through Welsh Government
	Licence fee payable to	N/A	Welsh Government

Control & Issue of Aquaculture Licences by License Type		**To 12nm for Fixed Gear Aquaculture**	**To 12nm for Seabed Cultivation ('ranching')**
Open Waters	**License Type**	N/A	**General Fishing Licence or MUS 2 Licence –** in relation to sourcing mussel seed stock
	Control / Issuer	N/A	MMO / WG
	Licence fee payable to	N/A	License seller for general fishing licence and No fee for MUS 2
Within marine renewable energy sites	**License Type**	**Crown Estate Lease** (but only if this can be separated from the marine renewable energy developer/operator lease or in combination with them)	TCE do not cover leases for 'ranching' (relaying/dredging shellfish). Public Right to Fish as seabed lease confers no rights to shellfish
	Control / Issuer	The Crown Estate	N/A
	Licence fee payable to	The Crown Estate: No application fee; annual rent reviewed every 5 years	N/A
Within marine renewable energy sites	**License Type**	**Marine License** from NRW for deposition of equipment where not exempt (e.g. hazard to navigation) – MCAA 2009 – otherwise Notification of an exempt activity form still required.	N/A
	Control / Issuer	NRW	N/A
	Licence fee payable to	NRW in Wales or MMO in England	N/A
Within marine renewable energy sites	**License Type**	N/A	**Fishery Orders (Regulating & Several)** - Sea Fisheries (Shellfish) Act 1967 - to 6nm – but may require marine renewable energy developer/operator to be the grantee
	Control / Issuer	N/A	Welsh Ministers through Welsh Government
	Licence fee payable to	N/A	Welsh Government

9.4 Aquaculture Parks – Potential Blueprint for Mariculture in Tidal Lagoons

9.4.1 Aquaculture Park Concept

Section 9.2 describes some of the drawbacks that have been described by current offshore renewable energy operators in terms of co-location with other commercial activities and other difficulties that could be envisaged specifically with respect to tidal lagoons. Whether real or perceived, what is certain is that to date there has been very little commercial co-location undertaken at marine renewable energy sites, mainly wind farms at present, with other commercial activities such as marine aquaculture. Discussions during the course of previous co-location work with existing offshore wind farm operators has revealed that, whilst they acknowledge the fundamental sense in allowing co-location, a lack of any legislative or policy driver requiring them to consider co-location has meant that this is not considered a priority from their perspective.

It is clear from the review of Marine Licensing for aquaculture activities described in Section 9.3, that in legislative terms it would be very difficult to issue separate licences for marine renewable energy production and aquaculture activities within the same spatial footprint. Given the previous reticence of marine renewable energy operators to participate in co-location, going forward, a new approach is therefore required with marine licensing whereby the overall control and coordination of co-location activities rests solely with the main stakeholder, which in this case is clearly the marine renewable energy developer and operator. Such an approach should help to increase the confidence of marine renewable energy developers/operators that they can participate in co-location activities, with their inherent Corporate Social Responsibility (CSR) benefits, without putting at risk their core operations.

This report proposes the adoption of an 'Aquaculture Park' approach to the development of mariculture activities within the proposed tidal lagoons. In this study the term 'Aquaculture Park' is used to describe a working arrangement whereby the main stakeholder, in this case the marine renewable energy developer/operator, is granted the licence to undertake a secondary co-location activity, in this case mariculture operations, within the spatial footprint of the marine renewable energy site, together with the right to sub-let the licensed areas for co-location activities to selected specialist partner organisations, in this case aquaculture producers, whilst providing specific services to those partner organisations. The current study presents Tidal Lagoon Swansea Bay as a case-study in how such a cooperative Aquaculture Park approach might be implemented and organised.

9.4.2 Marine Licensing and Aquaculture Parks

As described in Section 9.3 there is differing legislation and licensing for seabed cultivation (e.g. mussel 'ranching') and fixed gear aquaculture (e.g. suspended rope-mussel cultivation). Previous leases by The Crown Estate (TCE) for offshore marine renewable energy sites, offshore wind farms in the main, have not granted rights for the developer or operator to undertake any aquaculture activities within their sites.

It seems likely therefore that the granting of a TCE lease specifically for the development and operation of a tidal lagoon would preclude TCE from then granting later leases for fixed gear aquaculture activities within the marine renewable energy site. As such therefore it is vital that when a lease is issued to a marine renewable energy developer that this lease includes the right to carry out wider economic activities i.e. other than purely electricity generation. Given that the marine renewable energy developer is unlikely to also be an aquaculture operator, then it would be sensible to allow the marine renewable energy developer/operator to sub-let their rights and obligations under this lease, thus allowing them to partner with specialist aquaculture organisations capable of operating fixed gear shellfish equipment in a safe and responsible manner.

With respect to ranched shellfish within a marine renewable energy site, one suggestion that was put forward by Syvret *et al.* (2013) with respect to Fishery Orders was the possibility of issuing a Fishery Order in the form of a Regulating or Hybrid Order where the grantee or co-grantee was the wind farm operator. The wind farm operator might then be able to license others under the Order to conduct a shellfish cultivation business involving the deposition of shellfish on the seabed whilst retaining rights of ownership. Syvret *et al*. (2013) concluded that this option would require investigation to see if this would be possible.

9.4.3 Aquaculture Park Service Provision

The services envisaged as being supplied by the main licence holder, in this case the marine renewable energy developer/operator, could include the following:

- **Provision of aquaculture equipment;** This would most likely be the supply of generic production equipment that could then be used to on-grow a variety of shellfish or macroalgae species. The most obvious example would be the provision of buoyed headlines secured by anchors or weighted blocks. The supply and control of timing of known specification, high quality on-growing equipment would help to reassure the main licence holder that equipment being used remained serviceable, was maintained regularly and was replaced at set intervals thus helping to ensure that equipment failures and potential for impact on the marine renewable energy assets, such as the turbines, is minimised.

- **Hire facility for capital assets;** The closed nature of the tidal lagoon means that it will be difficult, although not impossible, to bring large aquaculture equipment onto site after the lagoon becomes operational. With the Aquaculture Park concept, the main licence holder would supply certain services, such as service vessels (for moving moorings etc.), as part of the rental cost of the site or on a cost per use basis. This would mean that start-up costs were relatively low for new aquaculture industry entrants, thus de-risking the enterprise, whilst providing reassurance to the licence holder that any movement, maintenance etc. of aquaculture equipment was carried out regularly in a safe and controlled manner and in compliance with the standards required within a marine renewable energy site.

- **Co-operative on-shore facilities;** The landward infrastructure of the tidal lagoon, in addition to a shellfish hatchery, could also provide a potential space for the development of shared processing, grading, depuration and dispatch facilities. These facilities might be supplied by the main licence holder as part of the sub-letting arrangement, again lowering start-up costs and de-risking new aquaculture enterprises.

- **Administration of other Licensing and Permissions;** Bivalve shellfish grown for human consumption within aquaculture production sites require a Shellfish Classification under the Shellfish Hygiene Directive due to their potential to bioaccumulate microbial contaminants. There are examples in setting these Classifications whereby surrogate species are used to provide a sample for analysis for Classification purposes. The native blue mussel, *Mytilus edulis*, is often the species chosen for use in this respect when it may be difficult to regularly obtain samples of the species being Classified. It would seem reasonable that the areas available for aquaculture within the tidal lagoon could have a similar approach implemented, based on a common Sanitary Survey, whereby all sites were 'pre-Classified' prior to the commencement of aquaculture operations thereby simplifying the process involved in establishing a new aquaculture operation.

  There are also other various licenses and permissions required for aquaculture operations. These include authorisation as an Aquaculture Production Business (APB) through Cefas, drawing up and implementing Biosecurity Management Plans which deal with alien and locally absent species, whilst site specific implications of designations under measures of the Habitats Directive (e.g. Special Areas of Conservation and Special Protection Areas) also require consideration. It would seem reasonable, that in the same way that Classifications could be centrally administered, then the main licence holder could also arrange for the other legislative permissions to be obtained thus allowing responsible aquaculture operators a fast-track approach to beginning aquaculture operations.

- **Environmental Monitoring;** The licence holder will most likely be required to closely monitor environmental conditions within the tidal lagoon. This monitoring might be further extended to include variables of interest and use to mariculture operators e.g. presence of harmful algal blooms, *E. coli* levels.

9.5 Conclusions

The Aquaculture Park concept is one that could help to provide a blueprint for co-location activities within offshore marine renewable energy sites where there is an incentive, desire or requirement by the renewable energy developer/operator to undertake such co-location activities. Specifically, the Aquaculture Park approach could help to provide the following:

- A marine licensing framework for aquaculture activities within marine renewable energy sites, in this case tidal lagoons.
- Through the provision of services, help to reassure the marine renewable energy operator that conflicts with other users can be mitigated against.
- Provide solutions to some of the practical issues potentially associated with carrying out aquaculture operations within a closed water mass used for energy generation whilst de-risking and lowering the capital costs associated with establishing new aquaculture operations.

In practice, by adopting the Aquaculture Park approach, the marine renewable energy company then controls where equipment can be deployed, maintenance schedules, fallowing of sites, deployment and movement of aquaculture equipment. This means that the marine renewable energy company has security of access to the lagoon for maintenance dredging etc. and helps ensure that kit is well maintained and so less likely to break free and end up impacting upon energy production operations. The marine renewable energy company owns the major assets such as an aquaculture service vessel for activities such as deploying screw anchors or weighted block anchors for securing aquaculture production kit. The return to the marine renewable energy company could either be through a rental agreement and/or some share of profits.

The proposed development of a tidal lagoon in Swansea Bay provides an ideal opportunity to demonstrate that co-location of marine renewable energy and aquaculture can take place. The Aquacoast project, being promoted by the Port of Milford Haven, also has some similar parallels to the Aquaculture Park concept in terms of looking to create a partnership approach to developing aquaculture within ports. Both the current project and the Aquacoast project presented these concepts at a Seafish Aquaculture Common Issues Group (ACIG) meeting held in September 2016. Further information about these presentations can be found at http://www.seafish.org/media/publications/SeafishACIGFinalMinutes_Sept2016.pdf

The Aquaculture Park concept is presented in this report as a model whereby the marine renewable energy developer/operator can mitigate against the risks potentially associated with co-location with aquaculture, through the provision of services help retain control over and input into other commercial activities taking place within its spatial footprint whilst allowing efficient, sustainable and economic use of the marine spatial resource for both its own and the wider Welsh economy's benefit. The case study for TLSB described in this report shows how this might look in practise.

SECTION 10 – DISCUSSION AND CONCLUSIONS

10.1 Introduction

This study has endeavoured to provide an overview of the potential methods and species for aquaculture that may be viable within a marine enclosed water body using Tidal Lagoon Swansea Bay (TLSB) as a co-location case study.

However, with TLSB, the delay in any final decision about whether the proposed lagoon in Swansea Bay will go ahead, has significantly impacted operational planning by TLSB and therefore their ability to provide the Authors with detailed spatial and operational information. Louise Strack, Development Manager at TLSB (pers. comm.), has stated that final details in terms of specific design of key areas won't be available until the marine contractor is appointed.

In the same way, information relating to the extent, regularity and type of maintenance dredging to be undertaken will not be available until a contractor has been appointed. This type of information is central to the ability to accurately describe where different species might be grown and what cultivation systems could be considered. Until such detailed information becomes available, the current report therefore considers and presents an overview of the aquaculture species and techniques that could be considered in enclosed water bodies such as the proposed lagoon at Swansea Bay.

This overview supports the more detailed spatial planning analysis presented in the Matrix comparative assessment of species vs. environment (see Section 2 and Appendix 1).

10.2 Environment

Swansea Bay is a hyper-tidal environment with a tidal range approaching 8.5 m on a mean spring tide and with an associated neap range of approximately 4 m. During mean spring tides, current speeds within the proposed lagoon site would be up to approximately 0.4 m per second in the southern area of the lagoon and up to 0.2 m per second in the northeast area of the lagoon (Source: ABPmer). Whilst the tidal rises and falls within the lagoon and relative extents of the inter and subtidal ranges will remain similar to baseline, the final layout of other facilities, such as for recreation, are yet to be confirmed (Louise Strack, TLSB pers. comm.) which makes it impossible at this stage to describe in detail the placement of suspended mariculture cultivation activities.

In terms of wave action within the proposed lagoon, modelling carried out by ABPmer showed that wave height would decrease significantly within the lagoon as a result of the sheltering effect of the wall. The seabed area within Swansea Bay proposed for the tidal lagoon is characterised by sediments consisting mainly of gravel to the west and south of the site and sand with varying amounts of gravel to the north and east of the site (Source: ABPmer).

In terms of shellfish hygiene standards after lagoon construction, the proposed 1.5 km main sewage outfall extension, which would take the outfall outside the lagoon, would result in *E. coli* levels of between 0 to 500 per 100 ml of seawater together with reductions in Nitrogen levels below the current baseline. This would most likely result in a Shellfish Classification of between A to B, which is suitable for the cultivation of bivalve shellfish and seaweed for human consumption.

10.3 Macroalgae Cultivation

There are three possible environments within the tidal lagoon that might be considered for macroalgae cultivation. These are the intertidal area, subtidal area and on the tidal breakwater. The intertidal area provides a good potential opportunity for seaweed cultivation although at present TLSB are unable to define the extent of the intertidal area that would be created after the lagoon has been constructed.

A suitable species for cultivation within the intertidal zone using seeded nets could be *Porphyra* spp. This species grows as thin, fast growing sheets and is tolerant to very high light and desiccation. It has high value as a food and is used to make nori sheets or the local Welsh delicacy known as laverbread. *Porphyra* is also used in South Wales as an ingredient in value added products such as processed snacks. The ability to grow *Porphyra* within the lagoon will depend on the physicochemical characteristics of the water body as well as turbidity levels, in terms of light penetration, and suspended solid levels in terms of the potential for smothering.

Initial indications are that the subtidal environment within the lagoon may be suitable for *Porphyra* cultivation provided that turbidity and suspended solid levels are not too high. It is likely that the best location for cultivation within the proposed lagoon would be near the turbines and to the west of the lagoon where the flow speed and therefore nutrient availability will be highest. Subtidal on-growing of *Porphyra* can be carried out on floating or semi floating nets attached to buoys or rafts and then placed in water deep enough to allow constant immersion, or in shallower waters allowing emersion at low tides.

We also suggest that the lagoon wall itself may serve as a suitable substratum for these species and that areas within a few metres depth of MLWS could be suitable sites for suspended seaweed cultivation. The benefit of this approach is that access could be by vessel or along the lagoon wall and in this way, any environmentally sensitive areas within the intertidal zone could be avoided completely.

10.4 Bivalve Cultivation

The Matrix (see Section 2 and Appendix 1) allowed us to analyse a combination of possible bivalve species that may be viable at this site. The picture presented by the Matrix generally indicates that the proposed lagoon would be a suitable site for bivalve shellfish cultivation in both the intertidal and subtidal zones. The current lack of detailed information regarding the relative size of these zones does mean however that it is difficult to predict quite how much space will be available for mariculture activities and importantly, what types of on-growing equipment can be utilised.

Sections 1.2.5 and 10.2 describe the likely Shellfish Classification standard that might be expected within the lagoon. This is the single most important aspect of whether bivalve shellfish cultivation should be carried out at a new site. The potential for a Class A status would place the lagoon within what is only 1-2 % of shellfish waters within the UK. This would give Food Business Operators using the lagoon an advantage in terms of reduced post-harvest processing requirements, more ready access to the retail multiples as well as marketing/branding advantages.

Of course, with any new site it is important to carry out pilot-scale cultivation trials before any moves towards and investment in commercial-scale operations are undertaken. These pilot-scale trials would help to assess both system performance and species performance in terms of mortality and growth rates. These trials would also allow a Shellfish Classification to be established for when commercial production and sale of product commences.

10.5 Spatial Planning Tools for Aquaculture

Spatial planning tools for aquaculture should be used to help support decision making for managers or prospective farm developers. Section 6 of the current report describes both regional level and site level examples of where aquaculture might be sited both at present or potentially in the future as technology and operational practises change or where the economics of production of species change e.g. with increasing price for products.

Whilst these spatial planning tools and analyses offer much to managers, regulators and developers, they may face limitations where data is unavailable or inaccessible. For example, our analysis of the MHPA area of interest highlighted that spatial data on environmental variables may not exist and the raw point data from monitoring programmes may not be readily accessible. For fine scale analyses such data will simply not exist at all. We were able to use what data was available to us and identified where, on occasion, they may act as proxies for missing data.

Milford Haven Port Authority is developing an ambitious project with academic partners in the UK and Ireland aimed at addressing these data gaps and developing a range of spatial models that include economic analysis. The Aquacoast project's stated aim is to support sustainable aquaculture development in Ireland and Wales, mitigating risk and increasing the attractiveness to aquaculture and ancillary businesses.

The web-based mapping tools developed for the Marine Plan projects in the UK's devolved administrations may offer an opportunity for further development of tools to assist aquaculture development. These are "live" sites and there may be an opportunity to develop, at a site level, more detailed layers and use these sites as a planning tool at that level. Certainly, this may be an option for the development of regional Aquaculture Parks that may have support from development agencies. These web-based tools lend themselves to both site scoping for a range of prospective developers and as a point of reference for stakeholder engagement in sites that have many activities.

Such spatial planning tools may not be necessary for sites such as tidal lagoons as these are essentially a blank canvas for development. Spatial analyses for lagoons will focus more on identifying applicable areas for individual aquaculture métiers which can be implemented on the desktop.

10.6 Aquaculture Parks

Within the current project, we are investigating the potential co-location mariculture opportunities that might be afforded by the proposed development of a tidal lagoon for renewable energy production within Swansea Bay.

Despite what may seem some mutual advantages to FBOs and marine renewable energy developers, there has to date been very few actual examples of commercial co-location carried out between these sectors, with the majority of co-location activities limited to pilot-scale or research projects.

In terms of Marine Licensing for aquaculture activities, in legislative terms it is very difficult to issue separate licences for marine renewable energy production and aquaculture activities within the same spatial footprint. Previous reticence by marine renewable energy operators to consider co-location would suggest that a new approach to marine licensing is needed which gives confidence to the main stakeholder that their core operations won't be impacted or adversely affected by secondary co-location activities such as aquaculture.

An 'Aquaculture Park' approach is presented within the current study as a means by which successful co-location of offshore renewable energy and mariculture might be achieved. We use the term 'Aquaculture Park' to describe a working relationship whereby the main stakeholder, in this case the marine renewable energy developer/operator, is granted the license to undertake a secondary co-location activity, in this case mariculture operations, within the spatial footprint of the marine renewable energy site, together with the right to sub-let the licensed areas for co-location activities to selected specialist partner organisations, in this case aquaculture producers, whilst providing specific services to those partner organisations.

The services provided by the main stakeholder could include the provision of high quality aquaculture equipment maintained under defined service schedules; hire facilities for high cost capital assets such as aquaculture service vessels; co-operative on-shore facilities; central administration of all licensing and permissions including Shellfish Classifications, Biosecurity Management Plans, Aquaculture Production Business licence; environmental monitoring.

The current study presents Tidal Lagoon Swansea Bay as a case-study in how such a cooperative Aquaculture Park approach might be implemented and organised within offshore marine renewable energy sites where there is an incentive, desire or requirement by the renewable energy developer/operator to undertake such co-location activities.

The Aquaculture Park approach should help to provide a marine licensing framework for aquaculture activities within marine renewable energy sites; through the provision of services help to reassure marine renewable energy operators that conflicts with other users can be avoided; allow them to retain control over and input into other commercial activities taking place within its spatial footprint; provide practical solutions to carrying out mariculture operations in closed water bodies; de-risk and fast track new mariculture operations thus helping to increase the chances of inward investment into a sector that has previously struggled to attract funding. Such an approach therefore provides a blueprint for how marine spatial resources can be most efficiently utilised for individual commercial organisations as well as the wider Welsh economy.

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APPENDIX

List of Appendices

APPENDIX 1 – MATRIX

COMPARATIVE ASSESSMENT OF SPECIES VS. TIDAL LAGOON ENVIRONMENT

REFER TO SEPARATE ELECTRONIC DOCUMENT ENTITLED:

SIF – Matrix TLSB – Progress Report 2 – Ver. FR2.0

1 APPENDIX 2 – OPERATIONAL PLANNING AND INFRASTRUCTURE – GENERAL CONSIDERATIONS

Introduction

Appendix 2 presents the results of operational planning considerations for the proposed tidal lagoon at Swansea Bay as considered by Tidal Lagoon Swansea Bay (TLSB) and the Authors of the current report. The questions posed (shown in black) by TLSB were originally formulated as part of a mariculture questionnaire to establish what mariculture activities might be possible in the proposed lagoon and how these might operate in practise. The responses (shown in blue) are by Martin Syvret of Aquafish Solutions Ltd. and Dr. Andy Woolmer of the Mumbles Oyster Company Ltd., main Authors of the current report. Some additions have been made to the original responses where further information has become available during the course of the current study.

Commencement of Mariculture Activities

Q. When could the mariculture facilities be established within the lagoon? Please consider whether this could be immediately post construction or if the lagoon would require time to establish its own fauna and if so how long?

A. It would be anticipated that pilot-scale trials could be commenced immediately post construction. It is even possible that certain amounts of the installation of cultivation equipment such as anchors for suspended culture could be carried out during the construction phase.

Required Environmental Conditions and Dredging Considerations

Q. Are any specific environmental conditions required? Please consider:

Water Quality *A.* In terms of the economic viability of shellfish farming operations, water quality is considered to be the most important variable dictating whether a farm can operate successfully. Generally, there is a requirement for a minimum of B Class harvest waters (based on CFUs of *E. coli*) in order for the sale of live bivalve shellfish to be considered economic.

Whilst the current regulatory Classification system is based on *E. coli* as an indicator of faecal contamination levels, in reality the major challenge in terms of shellfish hygiene is actually viral contamination. The current depuration processes are highly effective at removing low level bacterial loading within bivalve shellfish. Unfortunately, the binding action of viruses, such as Norovirus, within shellfish means that they are removed at a much slower rate than bacteria and, as yet, there is no effective practical method of removing viral contamination for farmed shellfish. Viruses can also survive for long periods in seawater especially when natural UV levels are low. Therefore, the point of discharge of the sewage outfall within Swansea Bay is critical and plume behaviour should be modelled to ensure that there would be no entrainment of effluent into the lagoon during power generation.

Suspended Sediments *A.* It is understood that maintenance dredging will be required periodically to ensure the optimal operation of the lagoon in terms of power generation. Dredging of this type can pose a challenge to aquaculture operations especially where shellfish are to be grown on the seabed. Consideration would therefore need to be given to ensuring that impacts of dredging on aquaculture operations are minimised e.g. dredging when the lagoon is being emptied.

It would also be worth considering fallowing of sites based on a stock rotation designed to match future dredging requirements. This could pose a challenge to aquaculture operators but with careful planning, and perhaps innovative equipment designs, it should be possible to manage sites so that stock and equipment are cleared from a site as dredging is required. This would of course therefore require spare space capacity above normal operational requirements and this should be factored in at an early stage of planning.

Detailed discussions with TLSB regarding maintenance dredging won't be possible until a contractor has been appointed which will not now be until 2017. However, early indications are that maintenance dredging won't be required until approximately Year 10 with anticipated dredging periods of 6 - 9 months at a time. Dredging would the probably be repeated every two years. The type of dredging equipment to be used may influence anchor choice for suspended aquaculture cultivation activities e.g. permanent screw anchors or traditional anchors/blocks that can be lifted and moved.

Spatial Footprints for Mariculture Operations

Q. What is the minimum area of lagoon water (intertidal and/or subtidal) needed to operate at 'pilot/research' or as a commercial business?

A. By targeting high value species, we predict that commercially meaningful returns can be achieved on relatively modest footprint areas.

Pilot-scale operations: The footprint required for pilot-scale studies is clearly not as large as that required for commercial operation. Pilot-scale cultivation could take place in multiple blocks of tens to hundreds of square metres. If these pilot-scale trials prove successful, then we would propose increasing the footprint to a commercial-scale activity. Possible pilot studies that could be potentially undertaken include (with sufficient space to adapt orientation and for access):

Intertidal native oyster trial:

- ORTAC cylinders – 50 x 50 m^2
- Intertidal bottom culture – 50 x 50 m^2

Subtidal native oyster trial:

- Seabed culture "ranching" – 100 x 100 m^2

Suspended cultivation:

- Floating pontoon/Floating cages – 50 x 50 m^2

Intertidal native clams trial:

- Direct growing on substrate with netting – 100 x 50 m^2

Access Requirements

Q. Is land access required? If so, please state what vehicles would be used, their number and frequency of visits (daily/weekly/monthly).

A. Land access would be required for intertidal sites for regular inspection, maintenance, collection for grading and harvesting.

Vehicle type will depend on the substrate type and size of farm operation; small sites could employ a quad bike with a trailer, and larger sites a tractor with a trailer.

Large-scale commercial oyster farm shown servicing French poche oyster bags

In the event that the intertidal area is unsuitable for vehicle access, i.e. too soft, then most cultivation activities can be equally well carried out using an aquaculture barge such as a French chaland or other small vessel

The use of the ORTAC system for intertidal native oyster cultivation would reduce the number of site visits as, unlike the French poche system, the cylinders do not require turning to remain free of fouling. Their placement at the Low Water Spring mark would mean that site visits would be approximately every 2 weeks. The use of low stocking densities could also be used to minimise site visits if this was required e.g. to meet environmental designation requirements.

With intertidal clam cultivation, cleaning of nets using tractors is only required when seaweed or fouling levels start to reduce water flow to the substrate. The frequency of cleaning is site and season specific but unlikely to be less that every 6 to 8 weeks during the main growing months and less in the winter.

Tractor with brush attachment

cleaning clam netting

Adapted tulip harvester used for

clam harvesting

Q. Is marine access required? If so, please state what vessels would be used, their size, number and frequency of visit (daily/weekly/monthly).

A. Marine access would be required for any suspended cultivation activities or subtidal benthic cultivation. Vessel type/design would be determined by scale and type of operation. We envisage that a suspended raft or headline system would require a small workboat with adequate deck space and lifting equipment. Similarly, subtidal seabed culture would require a workboat with the ability to deposit seed oysters and subsequently dredge market sized oysters.

Conceivably both roles could be undertaken by a single vessel such as an 8 m catamaran or specialist barge or chaland. The images shown are typical of aquaculture barges commonly used in European oyster cultivation. The chaland is generally used to service intertidal oyster racks. As the chaland would be used to service intertidal oyster racks then frequency of site visits would be the same as for land vehicles.

French oyster 'chaland' and similar flat bottomed vessel used in Devon

We envisage that vessel operations to a suspended system would occur at least 3 - 4 days per week depending on size of operation during growth phase with periodic increases in activity for maintenance and husbandry. Outside of harvesting and relaying, subtidal ranching requires fewer site visits other than for monthly monitoring.

Processing Facility Requirements

Q. Are processing facilities used? If yes, please provide details on the process and where it would take place.

A. Processing and associated facilities for modest shellfish aquaculture operations of high value species, such as those proposed, do not require very large buildings. We believe that a small light industrial unit or its equivalent with adequate outdoors space for vehicles and trailers would be adequate.

We envisage that an ideal facility would include a depuration centre for the post-harvest purification or depuration of shellfish. This process removes low level microbial contamination from shellfish to ensure highest possible product quality. Even where harvest waters are an A Classification, the use of depuration facilities is considered best practice in ensuring consumer protection.

Processing facilities would ideally be placed near to the area of cultivation so as to minimize travel distance and time to/from the cultivation area. Requirements for a processing facility are not necessarily limited to post-harvest activities but provide a site for regular grading and re-stocking of cultivation containers. Processing facilities can include equipment such as conveyor belts, shellfish washing equipment, shellfish graders and re-bagging machinery as well as post-harvest requirements such as modified atmosphere packaging equipment.

Buildings and Support Facilities

Q. What buildings and support facilities will you require? Where will these need to be situated with respect to the 'product'?

A. Buildings to house a depuration centre and processing equipment need not be large and these facilities can be accommodated in light industrial or agricultural buildings. Ideally these facilities would be close to the site of production to minimise travel time and length of time out of water for any shellfish being graded. Other facilities that could be considered:

Secure parking/storage for plant and equipment

Shared facilities for staff rest rooms; access to toilets and canteen facilities; refrigerated storage for shellfish; meeting rooms plus office space; possibly a farm gate sales area.

Q. Would the use of the facilities within the hatchery/laboratory be required? If so, please state requirements.

A. Access to a laboratory for aspects of end product testing for hygiene purposes but this can equally be done within the depuration centre if small clean rooms are incorporated.

Q. Please provide details of waste products involved and any means of collection/ recycling/disposal.

A. Waste products involved in shellfish aquaculture production are generally minimal. The main waste product for the species considered would be the mesh netting used for intertidal clam cultivation. This netting is replaced periodically as the size of the clams increases thus allowing mesh size to be increased which reduces the likelihood of fouling and requirement for cleaning. Depending on the material used for the net there may be the potential for recycling of old nets and we are already involved in net recycling schemes in the UK. Alternatively, this net can be disposed of as normal commercial waste i.e. there are no specialist requirements.

Staffing

Q. How many staff would be required on site? (daily/weekly/monthly)

A. This is dependent on production levels and the time of the year e.g. whether shellfish are being harvested for market. More staff will be required on site during harvest periods and during sorting/grading type activities. Some level of on-site staffing will likely to be required daily to ensure site security and to deal with routine maintenance activities etc. Office and administration support may well also be on-going during normal office hours.

Other Design Considerations

Q. Are there any requirements for features to be incorporated into lagoon design? E.g. moorings, step access to water etc.

A. There would be a need for moorings as some form of vessel based activity is likely. These vessels will also need access to a quay where stock can be loaded or unloaded. For small operations, it may be possible to launch and recover from slipways or use moorings for larger vessels but this is not ideal.

Tractors, quad bikes etc. will require safe access points to the intertidal area and shore based facilities. It is possible that vehicular access around the lagoon walls might allow direct access to cultivation systems such as cages placed on the substrate.

Spatting ponds would require access for vehicles. It would also be useful if the spatting ponds were within the reach of a boat/chaland mounted crane/HIAB as this would facilitate the transfer of seed shellfish from the ponds for cultivation within the lagoon.