Devon and Severn Inshore Fisheries and Conservation Authority

Mariculture Strategy

2021

Version 1: February 2020

Version 2 (current): March 2021

Contents

1. Introduction

Devon & Severn IFCA (D&S IFCA) is an organisation which will lead, champion, and manage a sustainable marine environment and inshore fisheries by successfully securing the right balance between social, environmental and economic benefits to ensure healthy seas, sustainable fisheries and a viable industry. In this context, and as set out in D&S IFCA's 2019–20 Annual Plan, D&S IFCA have developed this Mariculture Strategy to "*…highlight core areas where the IFCA may have the opportunity to work with the mariculture sector to evaluate and advance mariculture opportunities and provide information to those interested in entering this sector*".

Mariculture, within the context of this Strategy, is defined as: 'The cultivation of fish or other marine life within the marine environment', and therefore excludes cultivation of freshwater species, and cultivation in terrestrial facilities, which are beyond D&S IFCA's remit. In developing the Mariculture Strategy, D&S IFCA has consulted with key mariculture stakeholders within its District, attended multiple conferences and symposiums relevant to the current state of regional UK aquaculture, and conducted reviews of the relevant scientific, industry and policy literature.

The high-level aims of the strategy are set out in the 'Aims and Objectives' section (Section 2). Section 3 provides key information on the national and regional context in which this Strategy sits, and is followed by an outline of the current state of mariculture (Section 4). D&S IFCA have identified key actions by which the Aims and Objectives may be achieved and have suggested realistic timeframes in which they may be delivered. These specific actions are outlined with reference to the key challenges and factors influencing mariculture in D&S IFCA's District (Section 5), and the wider costs and benefits of mariculture (Sections 6 and 7). This strategy should be reviewed in its entirety on a biennial basis, to ensure the most appropriate support for, and development of, the mariculture sector.

Who is this Strategy for?

This Strategy not only serves to guide the mariculture-relevant work of D&S IFCA, but may also be used by the following parties:

- Individual mariculture producers, supply chain partners and their representatives
- Other legitimate users of the sea, including wild-capture fishers and their representatives
- Scientific research and funding partners including universities and private sector researchers and Cefas
- Regional bodies including local authorities and Local Enterprise Partnership (LEPs)
- Strategic mariculture interests including water companies and harbour authorities
- Regulators, Government bodies and other public bodies including the Marine Management Organisation, Defra, other IFCAs, the Food Standards Agency (FSA), the Environment Agency (EA), Natural England (NE), Seafish and The Crown Estate
- NGOs and wider civil society who have an interest in mariculture activities
- Developers whose activities have the potential to impact upon mariculture activities or the waters in which they are situated

2. Aims and Objectives

Management and Development Aims

To improve mariculture opportunities within D&S IFCA's District, within D&S IFCA's obligations under Section 153 (2) of the Marine and Coastal Access Act (2009) to:

- Seek to balance the social and economic benefits of exploiting the sea fisheries resources of the District with the need to protect, or promote the recovery of, the marine environment.
- Take any other steps which in the authority's opinion are necessary or expedient for the purpose of making a contribution to the achievement of sustainable development.
- Seek to ensure that the exploitation of sea fisheries resources is carried out in a sustainable way.
- Seek to balance the different needs of persons engaged in the exploitation of sea fisheries resources in the District.
- Further the conservation objectives of MCZs, limiting impacts of fishing activities/ mariculture on sensitive features within the MCZs spatial boundaries.

Engagement Objectives

- To understand the needs and requirements of current and prospective mariculturists in D&S IFCA's District so that they can be successfully included in D&S IFCA's planning and decision-making processes.
- To improve the D&S IFCA's knowledge of mariculture and potential for future developments.
- To ensure that D&S IFCA is recognised and heard within the District's mariculture community.

3. National and Regional Context

There is increasing interest, at local to international levels, in sustainable mariculture as a source of revenue and high-quality resources. Defra's 2015 Multi-Annual National Plan details how the UK Government will encourage sustainable growth in the sector through coordinated spatial planning (Defra 2015). The Multi-Annual National Plan highlights that the Marine Policy Statement is facilitating the formulation of Marine Plans (by the Marine Management Organisation) to ensure that marine resources are used in a sustainable way in line with the high-level marine objectives (Defra, 2015). These Marine Plans, including the South and South West Marine Plans, actively incorporate aquaculture production areas, with the aim of recognising aquaculture's place in supporting food security and livelihoods.

In England, the Seafood 2040 (SF2040) initiative and the Seafood Industry Leadership Group (SILG) have taken the lead on national-level strategy for aquaculture/mariculture. SF2040 represents a Strategic Framework to support a flourishing sector at the national level, which encompasses the Strategy's vision for investment and expansion of aquaculture/mariculture (Austin, 2018). SF2040 contains 25 recommendations, the delivery of which is overseen by the SILG in partnership with organisations such as Seafish, Defra, Cefas and the Seafood Industry Alliance. One of the 25 recommendations was to produce an English Aquaculture Strategy, which was subsequently released by SF2040 in November 2020 (Huntington and Cappell, 2020). The English Aquaculture Strategy sets out a vision and plan for aquaculture in England and supports a ten-fold increase in production by 2040, allowing the sector to become a significant contributor to increased seafood consumption. The Strategy also recognises a need for effective collaboration between industry and regulators to meet the challenges facing the sector. The strategy content was developed by Poseidon Aquatic Resource Management Ltd, working with industry representatives on the SF2040 Aquaculture Leadership Group (ALG).

At a regional level, the South West Marine Cluster Aquaculture Research Group have identified a range of attributes that make the South West a particularly attractive destination for mariculture, and aquaculture more generally (SWMCARG, 2019). The region has highly productive coastal waters with higher temperatures than the rest of the UK, which are particularly suited to shellfish and seaweed farming. There are many existing reception points for landing product, including some of the largest and most productive ports in England, including Brixham. Brixham is within D&S IFCA's District and has the highest landing value of all English ports. The ports and harbours also have strong onward distribution links, a high number of personnel with maritime and fisheries skills, and the region hosts various established mariculture operations. There is also a strong research and development presence with substantial marine science expertise, as well as a strong regional interest in the development and growth of mariculture. Mariculture is recognised as having the potential to:

- boost economic activity by creating employment and demand across multiple sectors
- build resilience in coastal communities, allowing diversification and improvement of livelihoods
- enhance 'ecosystem services' (the benefits that humans get from nature), and
- strengthen scientific capability through collaborative research.

In this context, regional strategies for supporting sustainable mariculture activities are increasingly in development. For example, the Dorset Mariculture Strategy (2020–2025) aims to highlight local opportunities to investors and prospective aquaculture stakeholders in Dorset. It conveys the information using a dedicated website containing signposting information and maps containing high resolution spatial surveys of habitat distribution, nutrient outflows, and subsequent suitability of differing spatial zones for specific forms of aquaculture.

It also contains a SWOT analysis for current Dorset mariculture, and has highlighted key actions points for moving the industry forward. This was developed with funding from the European Maritime and Fisheries Fund through Dorset and East Devon Fisheries Local Action Group and Dorset Coast Forum.

D&S IFCA recognises the importance of having a Mariculture Strategy for the District in terms of (a) an ability for the District to benefit from upcoming mariculture developments at a national scale, (b) promoting regional development of sustainable mariculture within the District, and (c) effectively balancing social, economic and environmental considerations in the exploitation of wild or cultivated sea fisheries resources. This strategy is a vital means to enable development of sustainable mariculture businesses within the District, and will be the first of its kind produced by an IFCA. It considers the options for intertidal, inshore and offshore cultivation, highlights examples of these within the District, and outlines limitations and opportunities that may arise.

4. Current Status of Aquaculture and Mariculture

4.1 World Aquaculture

In 2017, global aquaculture production of animals and plants was 111 million tonnes. This had an estimated value of $238 billion at first sale, having more than doubled in the ten years since 2008. European production equated to 3.08 million tonnes of production worth $14.45 billion. By comparison, 2017 global capture fisheries production at first sale was valued at $145 billion from 92.5 million tonnes of catch. Only 30.6 million tonnes (17.7%) of global aquaculture production was from the marine environment (FAO 2018, FAO 2019). The contribution of different finfish, shellfish and macroalgae (kelp and seaweed) species to world aquaculture is outlined in the Food and Agriculture Organisation's 2020 *State of World Fisheries and Aquaculture* report (FAO 2020).

4.2 UK Aquaculture

UK aquaculture production escalated in the 1980s, leaping from 200 tonnes in 1979 to 50,040 tonnes in 1990 (World Bank 2020). In 2017 total UK aquaculture production totalled 227,434 tonnes worth approximately £1.1 billion. This was primarily dominated by the Scottish aquaculture sector which accounted for approximately £1 billion in revenue and 90% of production, the majority of which stemmed from salmon mariculture in coastal net pens. Shellfish mariculture is also present in Scotland, and dominates the mariculture sector throughout the rest of the UK.

UK shellfish mariculture production in 2017 totalled around 18,000 tonnes worth a total £27 million. This increased in 2018 to around 21,000 tonnes worth £28.3 million. Despite this increase it is important to note that production and value of shellfish within the UK has fluctuated considerably over time, in 2013 the UK shellfish industry was worth £48 million with shellfish production approximated at around 26,000 tonnes.

The main shellfish species produced by sustainable mariculture in the UK are mussels (*Mytilus spp*.). In 2018 alone over 14,247 tonnes worth almost £16 million were produced. Pacific oyster *Magallana gigas* (formerly *Crassostrea gigas*) was the next most cultivated species with 2,220 tonnes produced worth almost £7 million. European oysters *Ostrea edulis* and Atlantic scallops *Pecten maximus* make up most of the rest of UK sustainable shellfish production (24 tonnes worth £172,756) *(pers. comm.,* Cefas; February 2020).

English shellfish production accounts for 16.8% of the UK total shellfish production at 2,764 tonnes worth an estimated £23 million. England produces 12.6% of the total UK harvested mussels, with 1793 tonnes produced in 2018. England also produces 43.4% of the total Pacific oyster production at 964 tonnes. Scotland produces 48% of the UK's mussels, and 40% of Pacific oyster production occurs in Northern Ireland. Native oyster production comes in at only 26 tonnes, with 7.5 tonnes produced in England.

UK finfish production is dominated by Scottish salmon farming. Rainbow trout are the next most-farmed finfish species, though most trout production occurs in freshwater or terrestrial recirculation aquaculture systems. Halibut and some wrasse species have also been farmed at small scale, with the wrasse farmed for use as cleaner fish in salmon aquaculture.

Macroalgal mariculture – the farming of kelps and other seaweeds – has high potential to provide algal biomass for products ranging from food to cosmetics, pharmaceuticals, biopolymers and biofuels. UK macroalgae have traditionally been wild-harvested and used for feed, food and fertilisers. However, wild harvesting is reaching its sustainable limit, and interest in macroalgal mariculture is growing in the UK: it is a potentially valuable source of biomass for food, fertilisers, biofuel and bioplastics, cosmetics and pharmaceutical products (Wood *et al.,* 2017). The most commonly cultivated seaweed species that could be farmed in the UK include sugar kelp (*Saccharina latissima*), oarweed (*Laminaria digitata*), winged kelp (*Alaria esculenta*), *Palmaria palmata* and *L. hyperborea* (Huntington and Cappell, 2020). UK culture of these species is in its infancy, and farming of those with a potential higher value and demand, such *Porphyra* and *Osmundea pinnatifida* is still at the experimental stage (Capuzzo *et al*., 2019).

4.3 Current Mariculture in Devon & Severn IFCA's District

The approximate spatial distribution of all mariculture in the D&S IFCA's District is shown in Figure 1, correct as of March 2021. Due to the nature of mariculture development this map may change considerably over time as businesses grow, cease trading or new mariculture developments arise. Shellfish production currently occurs primarily on the South Devon coast, in and around the mouths of estuaries and within large bays, notably Lyme Bay and Torbay. Methods of cultivation can vary considerably, even for the same species, based on personal preferences, and on the oceanographic and environmental characteristics of the site.

Currently, blue mussels and Pacific oysters are the only mariculture species being actively farmed and harvested within the D&S IFCA's District, although scallop ranching is being developed within Torbay (Figure 1). In 2018, production of both mussels and Pacific oysters in the District was valued at around £1.04 million. Of the total production 619 tonnes were mussels with an estimated value of almost £1,200 per tonne. Pacific oyster production in the District during 2018 totalled 123.9 tonnes with an estimated value of £2,500 per tonne. Production figures and estimated production values for the UK and D&S IFCA District were obtained from Cefas *(pers. comm.*, Cefas; February 2020)*.* Value estimates were based on the annual regional average price per tonne of product at first sale.

Mussel production in the District accounts for 35% of English mussel production, and 4.3% of the UK total (Cefas, 2020). The Offshore Mussel farm in Lyme Bay (see Figure 1) is the largest rope-grown mussel farm in Europe; projected production at full capacity is approximately 10,000 tonnes per year (Offshore Shellfish Ltd. 2020). Other methods of mussel cultivation include: harvesting from subtidal beds using an elevator harvester followed by re-laying of seed mussel (Exe Estuary), re-laying of seed and dredging on subtidal beds (Teign), and commercial harvesting by hand of intertidal mussel from public beds in the Taw-Torridge estuary SSSI. The latter occurs under an agreement with Natural England and D&S IFCA, with a harvest limit of 500 kg per month.

Pacific oyster production primarily occurs in estuaries on trestles, on the foreshore in bags or using the PARC system. Seed is typically imported rather than wild-gathered for these methods. Sites can be found within the Avon, Dart, Teign and Exe (Figure 1). Oysters in the Teign are gathered on the intertidal, and then re-laid on trestles or in bags for growth and subsequent harvesting. Oysters are farmed on the north coast of the District in Porlock Bay and within the Taw-Torridge estuary on trestles. Current regulation and management of mariculture within the District includes two Regulating Orders: the 2001 Waddeton Regulating Order and the 1996 Teign Regulating Order. Regulating Orders enable the holder to regulate fishing, dredging or otherwise taking of shellfish within the specified area. The 2001 Waddeton Regulating Order is held by D&S IFCA, with plots leased to shellfishers for the production of a range of shellfish species. In addition to Regulating Orders, particularly offshore, land can be leased from The Crown Estate for the construction of installations such as rope-grown mussel farms. Within estuaries, land may be privately owned by individual estate owners and leased to shellfishers for the cultivation of shellfish.

Native oyster farming, although carried out in Cornwall IFCA's and Southern IFCA's Districts, does not currently occur within D&S IFCA's District. Local mariculturists would like to farm native oysters due to their high value: in 2018, English native oysters sold at £3,500/tonne compared to £2,500/tonne for Pacific oysters (Cefas *pers. comm.,* 2020). However, local mariculturists believe that native oysters are less resilient to adverse conditions and are subject to higher mortality rates than Pacific oysters. This perceived unreliability makes them a potentially high-risk investment. Native oysters tolerate a narrower environmental niche than Pacific oysters and are therefore more vulnerable to suffering higher mortalities when environmental conditions become unfavourable over extended periods of time (Laing *et al*., 2006). Despite this, native oysters are being successfully farmed in several sites in the south of England (e.g. in the Fal estuary and Portsmouth Harbour; Cefas, 2020). There is also a strong regional and national drive, through organisations like the Native Oyster Restoration Alliance (NORA), to promote the recovery of native oysters, both as a food source and for their role in habitat creation. Drivers like NORA may well be a pathway for facilitating native oyster mariculture within the District, through either funding or support (Pogoda *et al*., 2019).

Mariculture of shellfish, finfish and macroalgae in the D&S IFCA's District is supported by the South and South West Marine Plans. These Marine Plans have identified many areas of mariculture potential, including for macroalgae and finfish, which are not currently farmed in D&S IFCA's District. However there is an increased interest in macroalgae developments within the District and Marine Licence Applications have submitted to MMO to which D&S IFCA responds. Whilst this currently represents a particular gap in mariculture activity but, like all mariculture proposals and areas of mariculture potential, would be subject to site-specific considerations regarding suitability and feasibility. Macroalgae are successfully farmed in the inshore waters off Cornwall and Dorset. Culture of marine fish species occurs nearby in Dorset, where lumpfish are produced for use as cleaner fish in Scottish salmon farms. A wild-capture live wrasse fishery occurs in D&S IFCA's waters (Plymouth Sound), where wrasse are captured alive and transported to Scotland for use as cleaner fish in salmon farms. Due to the method of wrasse capture and storage, each fisher is registered as an aquaculture production business. Trout are farmed in onshore and freshwater systems in Devon and Somerset; trout can be grown on in marine farm systems, but the only UK-based marine farming of trout currently occurs in Scotland.

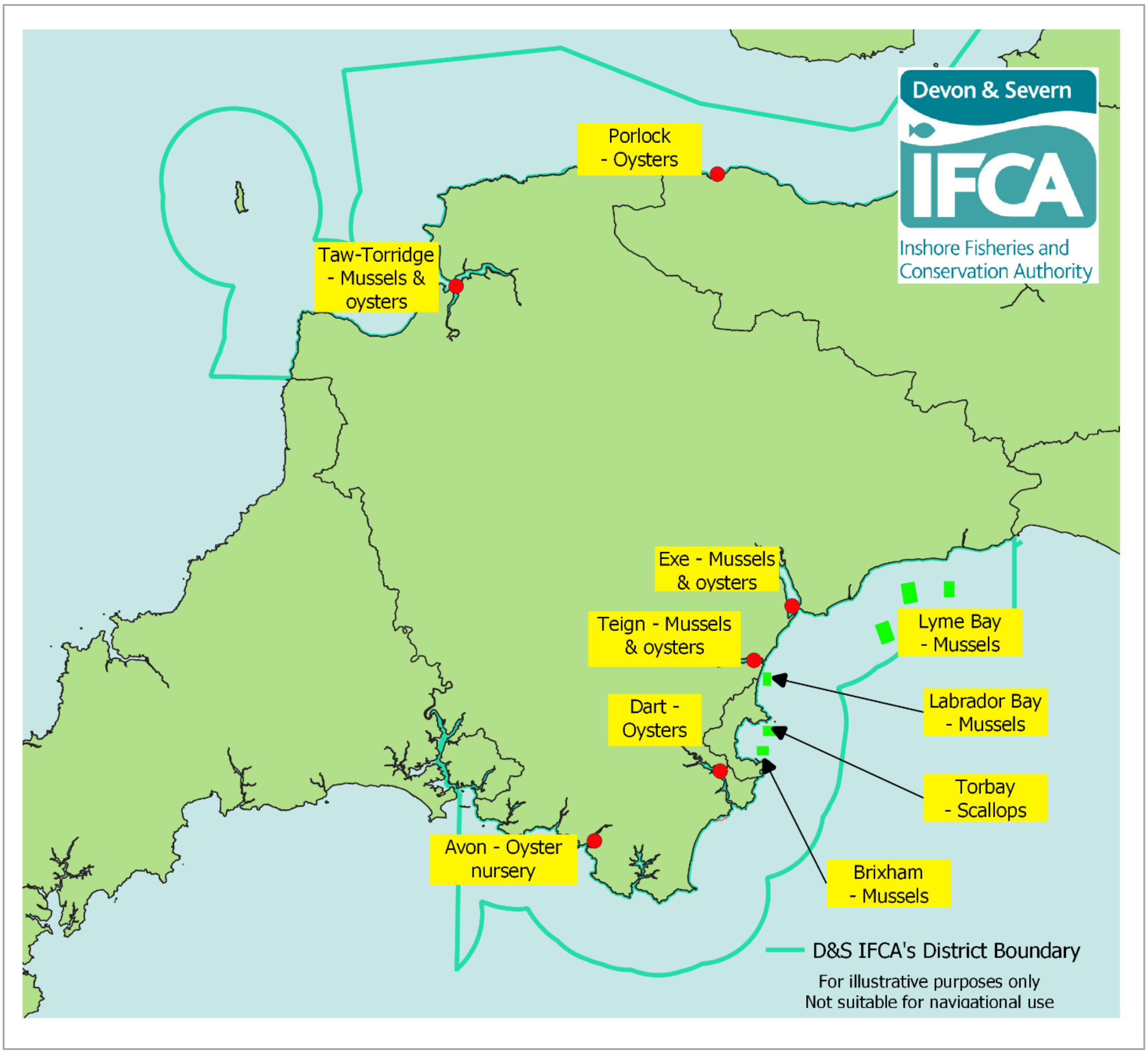

Figure 1: Locations of current mariculture production areas within Devon and Severn IFCA's District.

5. Factors Influencing Mariculture in the D&S IFCA's District

As part of the development of the Mariculture Strategy, D&S IFCA consulted with key mariculture stakeholders within its District, attended multiple conferences and symposiums relevant to the current state of regional UK aquaculture, and conducted reviews of the relevant scientific, industry and policy literature. This research highlighted a range of opportunities and issues facing the mariculture sector, which are outlined in this section.

Due to the diverse nature of mariculture, the challenges faced by the industry are usually site- and species-specific; for example, estuarine and offshore mariculture will face some differing challenges, as will, for example, shellfish mariculture versus macroalgal mariculture. Similarly, different forms of mariculture will have differing ecological and physical impacts on their surrounding environment. Therefore, highlighting specific issues and synergies relevant to both the nature and spatial location of any current and proposed mariculture within the D&S IFCA's District is an important component of this Mariculture Strategy, which aims to facilitate the growth and development of mariculture within the District.

This section also includes key actions for D&S IFCA which it is hoped will support sustainable mariculture; these actions are also listed in Annex 1. A key consideration is that collaborative relationships between industry, researchers and external agencies can play an instrumental role in encouraging new entrants to the mariculture sector, and enhancing existing operations (Grebe *et al.,* 2019). The importance of this collaborative approach has been taken into account in the actions outlined here.

5.1 Marine Plans, Licencing and Assessment

Proposed mariculture activities must take account of the relevant Marine Plan (South or South West Inshore Marine Plans) and may require a marine licence from the MMO. Marine licence applications must be evidence-based and demonstrate that the proposed activity would not significantly affect other legitimate users of the sea, conservation status or navigation.

Shellfish mariculture activities are largely exempt from Marine Licencing (https://www.gov.uk/government/publications/marine-licensing-exempted-activities), but macroalgal developments still require a marine licence. Macroalgal mariculture is still relatively new in the UK, and Wood *et al.* (2019) have highlighted that there is little institutional experience of the methods and their potential impacts, which may result in a very cautious approach to licencing new proposals. Similarly, new entrants to the sector may lack relevant knowledge regarding the marine licence application process. In some cases these issues have imposed additional costs and other constraints on pilot or research projects, and disincentivised potential investors (Huntington and Cappell, 2020).

Proposed sites falling within a European Marine Site or Ramsar site will need to satisfy the requirements of the Conservation of Habitats and Species Regulations 2017 (as amended) and may need a Habitats Regulations Assessment (HRA), while those within an MCZ may require an MCZ Assessment. Natural England can provide advice on potential developments in Marine Protected Areas through a discretionary service.

Additional regulations, licencing and permitting conditions may apply. Annex 2 provides a Regulatory Framework outlining the organisations involved in developing and regulating an Aquaculture Production Business. It is important that each organisation/authority is consulted at the appropriate stage to gain the relevant permissions to proceed with the next phase of development/farming activity.

5.2 Water Quality & Human Health

Bacteria and viruses

Water quality may be the most important issue for all shellfish mariculturists within the District. Shellfish production can be negatively impacted, sometimes for significant periods of time, if high amounts of *Escherichia coli* register during official live bivalve mollusc (LBM) sanitary tests. *E. coli* is the proxy used for microbial contamination of shellfish. The relevant local authority, on behalf of the Food Standards Agency (FSA) and in conjunction with Cefas, carries out these tests on classified shellfish harvesting areas monthly in the UK, and prior to classifying new shellfish harvesting sites. FSA sanitary surveys are carried out prior to an area being classified for shellfish harvesting and assess the area or catchment that may impact the shellfish harvesting sites; they are a detailed source of environmental data relevant to the growth and classification of bivalve molluscs.

Shellfish harvesting sites are classified A, B, C or prohibited (closed to harvesting/ production), based on the levels of *E. coli* detected in shellfish flesh. The classification process is described here: www.food.gov.uk/business-guidance/shellfish-classification. In summary, the classification determines the level of treatment required before shellfish can be harvested for direct human consumption. All shellfish to be harvested must undergo a purification process, called depuration, unless from Class A beds. If tests of LBMs from a classified site show consistently high *E. coli* concentrations, then the site may be downgraded. Even for one-off exceptionally poor results, the site will be temporarily closed until *E.coli* levels have returned to the appropriate levels. The results of all active and historically farmed classified beds can be found at: https://cefas.cefastest.co.uk/cefas-data-hub/food-safety/classification-and-microbiological-monitoring/england-and-wales-classification-and-monitoring/shellfish-monitoring-results/.

Poor water quality leading to high *E. coli* readings within LBM flesh samples is influenced by several compounding factors, which primarily stem from agricultural run-off, discharge from effluent pipes, overflow drains, and from storm discharges from sewerage treatment works. However poor results can also be elevated by other factors such as natural variability, and isolated pollution incidents (Quilliam *et al*. 2011). There is evidence that improving water quality by reducing nutrient loads has a positive correlation with decreasing *E. coli* concentrations within LBMs (Quilliam *et al*. 2011).

Norovirus presents another challenge to the industry, particularly for cultivators of Pacific oysters. Detected occurrence of norovirus within shellfish flesh following a reported human illness can cause the temporary closure of a bed and reduce demand for the product. Testing for norovirus is not yet fully regulated for Pacific oysters, and current tests are regarded as unreliable indicators for potential danger to human health (Lowther et al., 2019). Recent research commissioned by the FSA highlighted that levels of norovirus within oysters had a negligible impact on transmission to humans getting sick, and that poor food hygiene and latent immunity was more significant for the transmission and effective contamination by the virus. This research also noted that norovirus levels were higher in foods like lettuce than oysters (Cook *et al.,* 2019., Lowther *et al.,* 2019).

Trace elements and toxins

LBMs such as mussels are adept at filtering large volumes of water and in so doing purify the estuarine or coastal waters. They do this through the passive consumption of organic and inorganic particles which is then fixed and excreted as faeces and pseudo-faeces, dense pellets which sink and settle on the substrate (Carlsson *et al*. 2010). However, this filtration process may lead to the bioaccumulation of trace elements such as heavy metals and other anthropogenically-sourced toxins within the flesh and organs of the mussel. In industrialised or developed areas such toxins may enter the water in increased quantities (Ruiz *et al*. 2011, Jovic *et al.* 2011). Therefore, situating shellfish mariculture sites away from such sources, and monitoring development near existing mariculture sites is vital for both food safety and business viability (Ruiz *et al*. 2011). Mussels can also act as an indicator species for water quality, with wild or planted mussel populations being used to detect biological contaminants, bacteria, viruses, toxins, and heavy metals at locations of interest (Jovic *et al*. 2011).

Monitoring water quality

Advanced monitoring programmes are in development that will help mariculturists to monitor and forecast water quality, to identify and prepare for events that could be detrimental to stock. For example, the ShellEye project (https://www.shelleye.org/About/For_Industry) has been developed to help forecast times of increased risk of microbiological events, for example, from *E. coli*, and is expanding into the detection and forecasting of Harmful Algal Blooms (see below).

	Actions	**Timeframe**
A4	Produce a comprehensive guide and online resource library (Mariculture Resource Pack) for new and existing mariculturists who are looking for development opportunities within the District. This pack will include the outline Regulatory Framework that applies to mariculture operators.	2021–2022; following appointment of GIS Officer (A2)
B1	Review and respond to all relevant marine licence applications and with regard to mariculture, to include: information on existing use of area consultations, ecosystem impacts, social and economic factors.	Regularly and as and when required
C1	Collaborate with agencies that are involved with projects that seek improvements to upstream management of agriculture and waste water discharges e.g. AMP 5, Catchment sensitive farming, text alerts.	Ongoing continued liaison as projects arise
C2	Liaise with the relevant agencies involved with the regulation of water quality to aid reporting of incidents of poor water quality that have affected shellfish businesses and production.	Ongoing – monthly/ annually
C3	Support the consideration of alternative testing and monitoring procedures to improve food safety whilst reducing the current limitations on shellfish productions.	As and when new methodologies for testing are developed
D4	Publish news items and relevant literature online to help keep mariculturists ahead and informed of relevant mariculture news. Build relevant information into Mariculture Resource Pack.	Ongoing, as and when information becomes available
D7	Engage with regulators such as Cefas, FSA, EHO, SAGB and ACIG to provide a conduit on issues and advances in mariculture to mariculturists in the District. Build relevant information into Mariculture Resource Pack and disseminate information to mariculturists.	Ongoing through regular meetings and updates

5.3 Harmful Algal Blooms

Bivalves consume large quantities of microalgae and, in doing so, can bioaccumulate high toxin concentrations when Harmful Algal Blooms (HABs) are present. HABs are large aggregations of toxin-producing microalgae. Recent research in the South West, under the project '*Assessing and Mitigating the risks of Harmful Algal Blooms to fisheries and mariculture*' (AMHAB), has shown that the formation of both *Karenia mikimotoi* and *Dinophysis spp*. HABs are driven primarily by prevailing summer weather conditions, with warm, sunny, calm weather increasing thermal stratification of the water column, which promotes HAB formation. Coastal water circulation is another key risk factor. Circulation to the west of the Start Point tidal front sometimes leads to influx of HABs (e.g. *K. mikimotoi*) from the shelf edge and Western Approaches to the English Channel. Different circulation patterns and greater mixing of the water column (as opposed to stratification) generally appear to lead to lower HAB risk to the east of Start Point (Brown *et al.* in press). Local environmental conditions such as wind (causing aggregation of HAB cells) and rainfall, land runoff and riverine nutrient inputs (fuelling algal growth) can also have some influence on HAB risk (Schmidt et al., 2018).

D&S IFCA's District stakeholders have expressed little concern about HABs. This is due to independent testing they conduct on their product before sale, and perceived lower occurrences of blooms in the summer months than in previous years when water quality was less well-regulated. However, HABs may increase in occurrence in future, with predicted warming climates and pulses of terrestrial nutrient input following increasingly high intensity rainfall events (Townhill *et al.,* 2018; MCCIP, 2020). In addition, the consequences of HABs can be severe. Human consumption of shellfish with high toxin loads can be fatal (Anderson *et al*., 2002; Townhill *et al*., 2018). There are several types of algae that can form HABs, and their toxins can variously cause Diarrhetic Shellfish Poisoning, Amnesic Shellfish Poisoning, and Paralytic Shellfish Poisoning, in addition to other toxic effects in shellfish and consumers. HABs can therefore have significant impacts on shellfish production, as the sale of affected shellfish is prohibited until toxins within the flesh return to safe levels.

Some microalgae species (e.g. *Dinophysis spp.,* and *Alexandrium spp.*) are capable of causing toxicity at low concentrations in 'low-biomass blooms' (>100 cells per litre of seawater), whereas others (e.g. *Karenia mikimotoi* and *Psuedo-nitzschia spp.*) are only toxic at higher concentrations in 'high-biomass blooms' (>150000 cells per litre). For most farmed shellfish species in England, toxicity tests are conducted once per month by the relevant Local Authority, on behalf of the FSA. Such testing is a requirement of Regulation (EC) No 854/2004, which sets official controls on products of animal origin intended for human consumption. Annex 2 of the regulation specifically describes the testing requirements for bivalves (European Parliament and Council 2004). Many farms in high risk areas like the English south coast are at heightened risk of HABs. Mariculturists have been known to supplement FSA testing with more regular private tests, particularly during the higher risk summer months, to ensure product safety (*pers comm*.).

In addition to on-site testing, research is underway to use satellite technology to detect impending high-biomass HABs, for example as part of the S3-EUROHAB project (https://www.s3eurohab.eu/), ShellEye (https://www.shelleye.org) and PRIMROSE (https://www.shellfish-safety.eu/). The project will use these satellite data to create a web-based HAB and water quality alert system that will be designed alongside marine managers and industry end users to enhance the marine monitoring of specific high-biomass HABs in the French-English Channel region. Existing 'real-time' monitoring involving traditional on-site sampling and satellite remote sensing provide current observations and show historical trends. However, they are unable to predict the occurrence/impacts of future blooms and have limited capacity to inform appropriate mitigation strategies (e.g. early harvesting of stock, strategic siting of new aquaculture infrastructure or fisheries conservation zones, targeting abatement of nutrient inputs). In addition, satellite-based systems are less able to detect low-biomass blooms of species such as *Dinophysis spp.*, which causes Diarrhetic Shellfish Poisoning and presents one of the greatest HAB threats to UK mariculture.

By contrast the AMHAB project is using site-specific monitoring (water and plankton sampling) and modelling (statistical hind-casting) to understand what environmental factors promote the risk of HABS occurring and impacting on shellfish quality (HAB toxin levels). The project will then build a risk map around the SW Peninsula that identifies where HAB impacts are likely to be high and more likely to reoccur (hotspots), and those areas where risk is low and infrequent. These statistical models and risk maps will focus on *Dinophysis spp*. in particular. Subject to further funding, this project may be extended to allow forecasting of HAB events over wider timeframes and spatial areas, including for future climate change scenarios in the UK.

	Action	**Timeframe**
A4	Produce a comprehensive guide and online resource library (Mariculture Resource Pack) for new and existing mariculturists who are looking for development opportunities within the District. This pack will include the outline Regulatory Framework that applies to mariculture operators.	2021–2022; following appointment of GIS Officer (A2)
C4	Continue liaising with HAB sensing organisations and projects (e.g. AMHAB, S-3 EUROHAB) to address and quantify the impact of HABs on the District’s mariculture.	Ongoing
D7	Engage with regulators such as Cefas, FSA, EHO, SAGB and ACIG to provide a conduit on issues and advances in mariculture to mariculturists in the District. Build relevant information into Mariculture Resource Pack and disseminate information to mariculturists.	Ongoing through regular meetings and updates

5.4 Spatial Conflict

Spatial Conflict with Existing Fisheries

Spatial conflict issues may affect both shellfish mariculture and macroalgal mariculture development within the D&S IFCA’s District. Coastal areas within the District are primarily fished by small scale artisanal fisheries using pots, nets and operating towed gear. They may see mariculture developments adjacent to or near their fishing grounds as a threat to their business and way of life. Offshore mariculture sites within the District have previously been subject to damage from towed gear vessels trawling through static infrastructure. Many demersal gear fishers have historic, community and economic ties to their trawling grounds and worry that mariculture could displace them over time. Much of the inshore waters in the D&S IFCA’s District are closed to demersal fishing gear (43% in the southern part of the District) and therefore there is a strong desire by the mobile gear fleet to maintain the open areas to allow their activity to continue. This concern has led to strong opposition of both current and future mariculture developments within the District. Previous action has been taken to facilitate dialogue between the sectors, but working solutions are yet to be identified.

There is also evidence of positive interactions with static gear fishermen and offshore mariculturists. The nature of static gear can allow for deployment of pots amongst some types of fixed mariculture infrastructure. Anecdotally, pot fishers have been noted to fish more heavily around and amongst the rope-grown mussel beds in Lyme Bay, possibly due to perceived aggregations of commercial species. The mussel farm at Lyme Bay is well spaced out which allows for easy manoeuvring for smaller vessels between the mussel lines. This is not always the case, and some mariculture sites may have much higher density aggregations of gear and stock, or infrastructure that is incompatible with multiple uses. Establishment or expansion of such sites may displace static pot and net users from the entirety of the area leased for mariculture; the effects of this displacement would have to be considered in any development.

Estuarine mariculture has generally negligible spatial conflicts with other fisheries users in D&S IFCA's District. Interaction with mobile gear is mitigated as mobile gear is not permitted within estuaries in D&S IFCA's District, and positive interactions have been noted with anglers who cite fixed gear, such as oyster trestles, as favourable locations to catch fish. Conflict can arise when intertidal private beds become exposed. It is difficult to display signage and warnings on these beds due to their position and the nature of the marine environment, and members of the public may engage in hand gathering activities on these private beds without necessarily understanding they are privately leased mariculture sites. This is a continual point of contention for some of the District's shellfishers.

Interactions between mariculture and fisheries are explored further in Sections 6 and 7.

Spatial Conflict: Pacific Oysters and Conflict with Protected Areas

In locations where wild pacific oyster densities reach high levels, designated features of MPAs are classed as at risk of declining into unfavourable condition or remaining classed as unfavourable by Natural England (NE). This has implications for current MPAs; for example, some features of Plymouth Sound and Estuaries SAC are deemed to be in unfavourable declining condition, largely due to the increasing presence of Pacific oyster (Natural England, 2018). Similarly, a 'recover' target has been suggested for the estuarine rocky habitats feature of the Dart Estuary MCZ, because Pacific oyster culture has been deemed to represent a significant pathway for the introduction of Pacific oyster as an invasive species (Natural England, 2020). There are concerns among some mariculturists that there is a lack of clarity on the effects that farmed Pacific oysters may have on the assessment condition of MPAs such as the Dart Estuary. If farmed Pacific oysters are deemed to cause a site to be unfavourable, this has significant implications for both the management of the MCZ and also any established or planned Pacific oyster farms.

Defra announced in late 2019 at Seafood 2040 that they have established a Pacific oyster policy focus group with input from NE and Cefas that will be investigating the positive and negative impacts associated with Pacific oysters over the coming years, as well as defining their overall policy on farming Pacific oysters (Seafood 2040, 2019). The resulting Cefas report, projected for delivery in March 2021, should provide clarity as to the true extent and nature of any ecological impacts presented by Pacific oysters and the regulatory framework in which they will be managed (Seafood 2040, 2019). Until the Cefas report clarifies this situation, the Defra group is not currently supportive of new Pacific Oyster farms (or extensions to existing farms) within MPAs or where they are locally absent (Huntington and Cappell, 2020). The current state of the scientific evidence is summarised in Section 7.

Natural England is leading the EMFF-funded Pacific Oyster Project, which aims to establish the extent of Pacific oysters in many of the South West's estuaries and determine the feasibility of eradicating them. The project came to an end in 2020, and a report is due in early 2021.

	Action	Timeframe
A1	Provide up to date maps of all current mariculture fixtures within the District: for public information and to clearly identify areas where other forms of marine development would not be encouraged by D&S IFCA. This information will be updated on D&S IFCA's website and used where appropriate in response to enquiries and consultations on marine developments.	2021–2022; following appointment of GIS Officer (A2)
A2	Highlight, through the production of maps, spatial zones where the existing use is low and the potential for future mariculture developments may exist. Fulfilment of this action will require the contracting of a GIS Officer based with D&S IFCA, who will map existing activities and other relevant information such as spawning and breeding grounds where possible, in order to also identify areas where other forms of marine development would not be encouraged by D&S IFCA.	2021–2022
A4	Produce a comprehensive guide and online resource library (Mariculture Resource Pack) for new and existing mariculturists who are looking for development opportunities within the District. This pack will include the outline Regulatory Framework that applies to mariculture operators.	2021–2022; following appointment of GIS Officer (A2)
B1	Review and respond to all relevant marine licence applications and with regard to mariculture, to include: information on existing use of area consultations, ecosystem impacts, social and economic factors.	Regularly and as and when required
B2	Submit recommendation for D&S IFCA's Byelaw and Permitting Sub-Committee for potential management of mobile gear activities to protect mariculture sites within the District.	2021-2022
D6	Use D&S IFCA's published maps and other relevant literature resources as a basis for preventing unwarranted interference in mariculture activities by those involved in projects to remove or eradicate Pacific oysters from areas in some estuaries which are classified for mariculture.	Ongoing
D8	Review new reports on wild Pacific oyster spread and its maintenance, and the potential impacts on MPA features	Ongoing

5.5 Public Perceptions

An issue of growing concern to local mariculturists within the District is the current negative perception of wild Pacific oysters. Pacific oysters were first grown in the UK in the 1890s (Humphreys *et al*., 2014). In 1960s the then Ministry of Agriculture, Food and Fisheries encouraged the development of Pacific oyster production to allow for diversification after the decline in native oyster populations. Pacific oysters are cultivated legally in the UK, but their wild counterparts are classified as an invasive non-native species. Legal instruments that apply to invasive non-natives such as the Pacific oyster include the Water Framework Directive, Habitats Directive, Marine Strategy Framework Directive, and the EU's Council Regulation concerning use of alien and locally absent species in aquaculture. None of this legislation prohibits mariculture of Pacific oyster, but tries to ensure its sustainable management, with the flexibility for authorities to take a locally-relevant risk-based approach to management.

However, within the general public there is a growing anti-Pacific oyster lobby due to their perceived threat as an invasive species. Some groups and individuals have raised concerns about negative implications of currently established wild pacific oyster populations within the

District’s current EMS and MCZ sites, and their potential to spread. Mariculturists are concerned that current efforts by environmental groups to remove wild, invasive Pacific oysters are not only unscientific and ineffective, but could indirectly result in farmed stock being targeted.

More generally, mariculturists should be mindful of the social licence for mariculture. In some cases, there is significant opposition to development applications from non-local stakeholder groups (Huntington and Cappell, 2020). There is some concern that, as a relatively new concept in the UK, mariculture may be publicly judged by different standards to other more traditional operations, even where the other operations may be more socially or environmentally costly (Huntington and Cappell, 2020). However, public perceptions and media portrayals of mariculture are generally becoming more positive and increasing social licence for these operations may be expected over coming decades (Huntington and Cappell, 2020).

	Action	**Timeframe**
A1	Provide up to date maps of all current mariculture fixtures within the District: for public information and to clearly identify areas where other forms of marine development would not be encouraged by D&S IFCA. This information will be updated on D&S IFCA’s website and used where appropriate in response to enquiries and consultations on marine developments.	2021–2022; following appointment of GIS Officer (A2)
A2	Highlight, through the production of maps, spatial zones where the existing use is low and the potential for future mariculture developments may exist. Fulfilment of this action will require the contracting of a GIS Officer based with D&S IFCA, who will map existing activities and other relevant information such as spawning and breeding grounds where possible, in order to also identify areas where other forms of marine development would not be encouraged by D&S IFCA.	2021–2022
A4	Produce a comprehensive guide and online resource library (Mariculture Resource Pack) for new and existing mariculturists who are looking for development opportunities within the District. This pack will include the outline Regulatory Framework that applies to mariculture operators.	2021–2022; following appointment of GIS Officer (A2)
B1	Review and respond to all relevant marine licence applications and with regard to mariculture, to include: information on existing use of area consultations, ecosystem impacts, social and economic factors.	Regularly and as and when required
D6	Use D&S IFCA’s published maps and other relevant literature resources as a basis for preventing unwarranted interference in mariculture activities by those involved in projects to remove or eradicate Pacific oysters from areas in some estuaries which are classified for mariculture.	Ongoing
D8	Review new reports on wild Pacific oyster spread and its maintenance, and the potential impacts on MPA features	Ongoing

5.6 Disease and Parasites

Farmed species can be vulnerable to diseases and parasites; however, these are not perceived as substantial risks by mariculturists in D&S IFCA's District. Due to shellfisheries current standard operating practices, such as operating with sustainable stocking densities, disease instances are largely prevented. Parasites have affected shellfish enterprises within the District before, notably high cockle mortalities in the Exe in 2011 due to infections of *Minchinia spp.* and *Himasthla spp.,* both of which cause 'gaping' in cockles. These infections closed the fishery before it had a chance to be properly established (Davies & Blundell 2019).

Native oyster farming, though carried out in Cornwall IFCA and Southern IFCAs' Districts, does not currently occur within D&S IFCA's District. A significant limiting factor for native oyster production is the restriction placed on the movement of native oysters from areas where the oyster disease *Bonamia ostreae* has been detected. The area between Start Point and Portland Bill is one of the few areas along the south coast of England that is free from *Bonamia* so movement into this area is restricted.

Another area of concern for many Pacific oyster farmers is the Oyster Herpes Virus (OsHV-1). Oyster herpes virus is a virulent disease affecting both juvenile and adult native and pacific oysters. The virus is most prevalent when water temperatures exceed 16 C (Renault *et al.,* 2014), and is associated with high mortality rates. The main prevention method is to restrict movement from infected areas to non-infected area (Arzul *et al.,* 2001). Cefas monitors areas for the virus should unexpected high mortalities be observed.

	Action	**Timeframe**
D1	Continue dialogue with current and prospective mariculturists within the District in order to keep abreast of industry concerns and progress and understand how mariculture interests can be furthered.	Ongoing
D7	Engage with regulators such as Cefas, FSA, EHO, SAGB and ACIG to provide a conduit on issues and advances in mariculture to mariculturists in the District. Build relevant information into Mariculture Resource Pack and disseminate information to mariculturists.	Ongoing through regular meetings and updates

5.7 Sedimentation and Marine Pollution

Sedimentation and marine pollution can adversely affect some types of mariculture, particularly benthic shellfish farming. High sediment loads over extended durations can smother and kill benthic shellfish species like mussels and Pacific oyster (Karel 1999, Mainwaring *et al.,* 2014, Hutchison *et al*., 2016). For estuarine oyster famers this sedimentation can be avoided by suspending shellfish above the benthos, using trestles and bags. Offshore mussel producers routinely suspend their product above the seabed, so are unaffected by sedimentation. By contrast, cultivated subtidal mussels are more at risk to sedimentation. Some of the District's mariculturists believe that dredging activities, and disposal of material from aggregate dredging, flood defence work and harbour maintenance actions (such as bed levelling) have caused considerable mortalities to their stock due to the close proximity of these actions to current shellfish production areas. If incorrectly disposed of, dredge spoil can have secondary affects in addition to smothering that can have negative implications for a range of species including bivalves.

Dredge spoil from areas of industry and marine development can contain high levels of trace heavy metals. Disposal at sea of such material can have deleterious consequences for nearby ecosystems and mariculture. Exposure to above average quantities of trace metals and suspended solids can have negative consequences for the overall health, growth, fecundity, and survivability of bivalves (Yang *et al.,* 2018). This has implications for rope grown bivalve mariculture in the vicinity of a dredging/disposal event.

These impact of marine activities, including dredging and disposal, are considered through the marine licensing process, during which the Applicant for a marine licence must consider environmental impacts of the proposed activity – often through an Environmental Impact Assessment or Habitats Regulations Assessment process. D&S IFCA play an active role in critically assessing marine licence applications, with a view to championing the interests of inshore fisheries and protecting the marine environment.

Hydrocarbon pollution is rare in the District, so is not a high-ranking concern to the District's mariculturists. Despite the low incidence rate of hydrocarbon pollution, individual events could have significant ramifications for mariculture should they encroach upon an active production site, particularly because static mariculture resources are unable to avoid exposure to local contaminants (ITOPF Ltd, 2014.) The effects of hydrocarbon pollution are largely determined by its physical and chemical characteristics and how these change over time, or 'weather', which in turn depends on local sea and climatic conditions (ITOPF Ltd, 2014). The local geographic and hydrographic conditions also determine the impacts of pollution events: pollutants may disperse more easily in open areas with strong currents but may accumulate in sheltered bays. Contaminants can induce sub-lethal behavioural changes, through to impacts such as reproductive depression and mass mortalities and can taint the taste of the final product (ITOPF Ltd, 2014).

Hydrocarbons can be taken up by marine life, causing mortality and/ or preventing sale of affected stock until hydrocarbon content returns to safe levels for consumption (European Parliament and Council 2004). The longevity of hydrocarbon retention within the affected species will vary depending on severity and duration of exposure and on local conditions; for example, metabolism (and therefore depuration) is lower in cooler conditions (ITOPF Ltd, 2014). Depuration rates also vary between species; hydrocarbon contaminants accumulate most readily in fat tissue, so shellfish or finfish species with a higher fat content tend to retain hydrocarbon contaminants for longer (ITOPF Ltd, 2014). Mussels can retain hydrocarbons for up to six months after exposure (Solé *et al.,* 1996), but the negative impacts can persist even after contamination is no longer detectable, for example reproductive success of mussels may be decreased for up to two years after a spill event. This has particular implications for mussel cultivators who depend on larval settlement within their production process to replenish stocks (Donaghy *et al.,* 2016).

Though mariculture of macroalgae and finfish are not yet established in the District, hydrocarbon spills could also impact their productivity. Macroalgae are, for example, vulnerable to smothering and oil toxicity (ITOPF Ltd, 2014). The literature on the potential effects of an oil spill on macroalgal mariculture is currently limited, but many studies have documented the effect of hydrocarbons on increasing fish mortality and interfering with fish development and physiology (e.g. Rice *et al.,* 2001, Stagg *et al.,* 2009). For example, following long-term exposure to low concentrations of weathered crude oil released in the 1989 *Exxon Valdez* oil spill, pink salmon fry suffered depressed growth rates, and egg mortality was elevated for up to four years after the spill (Rice *et al.,* 2001). Given the broad geographical range of impact of the *Exxon Valdez* spill, these findings are also applicable to nonpoint source pollution of urban estuaries (Rice *et al.,* 2001). The clean-up method also has a bearing on the impacts to mariculture: mariculture resources that may be less affected by a surface oil slick may become contaminated by oil droplets in the water column if oil dispersants are used.

The likely impacts of both the slick and subsequent clean-up methods to an offshore or costal operations could present significant short- and long-term barriers to continued production (ITOPF Ltd, 2014). These barriers are not limited to direct impacts on the product itself but also loss of public and market confidence following high-profile pollution events, as well as economic losses associated with cleaning of gear (ITOPF Ltd, 2014).

There are several national and local protocols set in place that coordinate responses to hydrocarbon spillages in order to mitigate damage to both the environment and property. These include Standing Environment Groups, which are usually comprised of members from several organisations, the EA, NE, IFCAs and frontline services like the police and fire services. These organisations typically convene for regional Incident Management Exercises and simulation days in preparation for an unexpected spill event. D&S IFCA attends these exercises for regions in its District (e.g. the Teign and Severn estuaries).

	Action	**Timeframe**
B1	Review and respond to all relevant marine licence applications and with regard to mariculture, to include: information on existing use of area consultations, ecosystem impacts, social and economic factors.	Regularly and as and when required
D1	Continue dialogue with current and prospective mariculturists within the District in order to keep abreast of industry concerns and progress and understand how mariculture interests can be furthered.	Ongoing
D7	Engage with regulators such as Cefas, FSA, EHO, SAGB and ACIG to provide a conduit on issues and advances in mariculture to mariculturists in the District. Build relevant information into Mariculture Resource Pack and disseminate information to mariculturists.	Ongoing through regular meetings and updates
D9	Liaise with Standing Environment Groups, Harbour Authorities and EA on their maintenance works and Pollution Action/contingency plans, and training/simulation incident management Exercises.	Ongoing

5.8 Climate Change

Although not an immediate concern expressed by the District's mariculturists, climate change in the form of ocean warming or ocean acidification could have long term implications for mariculture within D&S IFCA's District, and across the UK (Stewart and Wentworth, 2019). The long-term impacts of ocean warming, though potentially beneficial to temperature-tolerant farmed species like *M. gigas*, could negatively impact native temperate species like *M. edulis*. The District's estuarine and coastal waters, like many across western Europe, have been subject to gradual warming since the industrial revolution, with UK estuaries seeing sea surface temperature increases of 0.7°C between the years 1971 - 2010 with temperatures projected to rise a further 1°C - 4°C within the 21st Century (Lowe et al., 2009, Robins et al., 2016, IPCC 2014, MCCIP 2020). *M. edulis* typically occupies a temperature range from 5-20°C (Bayne et al., 1976, Bayne and Worrall 1980), with tolerances of higher and lower temperature extending to 29°C and -30°C degrees respectively (Seed & Suchanek, 1992, Read & Cumming, 1967).

Although heightened oceanic temperatures are tolerated by both juvenile and adult mussels, mussel larvae are significantly more susceptible to raised temperature and salinity pressures than mussels' post larval stages (Rayssac et al., 2010). With increasing temperatures, the larvae suffer not only higher mortalities, but also when subjected to temperatures over 18°C, slower growth rates (Rayssac et al., 2010). Milder winters have been shown to delay spawning on mussel populations in the Wadden sea (Nehls et al., 2006). This has the compounded effect of larvae and juvenile mussel settling later in the year when predator abundances are higher. As a result, the mussel seed and larvae are subject to increased levels of predation, a particular problem for substrate laid mussel. Such instances of decreased larval settlement can limit successful recruitment, inhibiting rejuvenation of established mussel populations. Macroalgal farming within the district could conversely benefit from increasing oceanic temperature rise as studies have shown how increasing oceanic temperature positively impacts macroalgal growth rates for some commercially viable species (Koch et al., 2013). This potentially creates an opportunity for prospective mariculturists to exploit during a time of dynamic oceanic change.

Ocean acidification is expected to increase over the next 100 years affecting both deep offshore waters and inshore coastal waters and estuaries. It will likely negatively affect farmed calcareous shelled bivalves like *M. edulis* and *M. gigas*. This is because molluscs are disproportionality affected by ocean acidification, particularly in the larval stages but also throughout development and maturity (Kroeker et al., 2013; Mangi et al., 2018; MCCIP, 2020). Not only does ocean acidification increase larval mortality, but it also affects the fecundity of the adult population (Talmage and Gobler, 2010; Parker et al., 2011; Kroeker et al., 2013). This is important for mariculturists who depend on collection of mussel larvae to re-seed their farmed beds or ropes. Ocean acidification also affects mollusc calcification rates (Talmage and Gobler, 2010; Kroeker et al., 2013; Mangi et al., 2018; MCCIP, 2020), this in turn can lead to higher mortalities in adults of both oysters and mussels and creates a more brittle final product for sale, which is at higher risk of spoiling. A recent study by Mangi et al. (2018) predicted between a 14% and 28% loss in net present value of UK aquaculture by 2100 as a direct result of increasing oceanic acidification within UK waters.

Despite some understanding of the impacts of climate change and ocean acidification on aquaculture, there are still significant knowledge gaps that need to be addressed to fully understand the true scale of impact on the industry. The Marine Climate Change Impact Partnership's (MCCIP) 2020 Aquaculture Report identified key areas of research needed to fill knowledge gaps. The priority topics included "examine the impacts of climate change on the environmental impacts of aquaculture – e.g. assimilative capacity of receiving water bodies, including impacts at potential offshore sites", and emerging topics such as "the capacity of aquaculture species at individual and population level to adapt to climate change and ocean acidification". For the full list of identified knowledge gaps refer to MCCIP (2020).

	Action	**Timeframe**
D1	Continue dialogue with current and prospective mariculturists within the District in order to keep abreast of industry concerns and progress, and understand how mariculture interests can be furthered.	Ongoing through regular meetings and updates
D7	Engage with regulators such as Cefas, FSA, EHO, SAGB and ACIG to provide a conduit on issues and advances in mariculture to mariculturists in the District. Build relevant information into Mariculture Resource Pack and disseminate information to mariculturists.	Ongoing through regular meetings and updates
D10	Keep abreast of the literature and Government advice regarding the impacts of climate change that could impact the mariculture industry.	Ongoing, as and when information becomes available

5.9 Finances and Other Food Production Systems

Mariculture can be resource-intensive in terms of capital, infrastructure, and personnel. Set up of any mariculture operation can require significant financial input, especially for larger projects, while maintenance of gear and tending of stock can be time intensive at all levels of the industry. This initial set up may prove a challenge to those unfamiliar with the industry who may be put off by the financial risks involved (Ahsan and Roth, 2010). Initiatives like the D&S IFCA's Waddeton Regulating Order are designed to provide a low-cost entry to the industry for new starters, those wishing to diversify, and a financially feasible opportunity for seasoned mariculturists.

The relative cost of energy, and how it changes over time, is likely to have a large impact on development in this sector, with high energy prices favouring less energy-intensive approaches, and vice versa. Most of the energy costs associated with finfish mariculture are embedded in feed production, from capture and production of raw ingredients to their processing and the distribution of feed products. Therefore, mariculture activities that do not require large external feed inputs, such as filter-feeding shellfish or macroalgal culture, may experience an advantage if energy prices are high. However, if energy process were to fall, feed-intensive and otherwise energy-intensive forms of production such as Recirculating Aquaculture Systems may be more economically competitive (Government Office for Science, 2017).

The cost and availability of raw material, particularly feed for finfish culture, and seed for shellfish, is also likely to play a role in determining the economic competitiveness of different forms of production. Feed typically represents 50–60% of the operating costs of a finfish culture business, and the prices of typical raw ingredients such as fishmeal and fish oil are projected to almost double over the coming decades (Msangi et al. 2013; Government Office for Science, 2017). These ingredients can be replaced in salmon feeds, but at the cost of reduced fish growth rates and poorer nutritional value of the end product (e.g. lower omega-3 content). New protein and oil sources are being produced that may overcome these issues and could become economically viable alternatives to fishmeal and fish oils, but these may be subject to lower public acceptance, particularly where genetically modified ingredients are involved (Betancor et al., 2015 ; Government Office for Science, 2017).

Fluctuations in the availability and pricing of the wild capture fisheries produce is also likely to impact the economic viability of mariculture produce, by affecting demand for price-competitive fish as well as the cost of fish meal and fish oil. Though capture fisheries are projected to stagnate over the coming decades, improvements in fisheries management and technological adaptation could ensure continued global supply of fish (Government Office for Science, 2017). Fluctuations in the price of fish meal and fish oil are likely to continue to impact on aquaculture and may depend in part on the global market's reliance on forage fish from South American fisheries, which are subject to periodic collapses in relation to climate events. However, fishmeal and fish oil are increasingly sourced from within Europe, and the supply of oil seed crops that can provide alternatives to these marine-derived components of fish feed are expected to keep pace with demand (Shepherd et al. 2017; Government Office for Science, 2017). It is important to note that the sustainability of terrestrially-derived alternative feed products is not certain and may reduce the overall sustainability of mariculture products by increasing land conversion and use, water use and nutrient pollution (Malcorps et al., 2019).

UK-based aquaculture systems have already shown instances of vulnerability to external markets, though these are hard to predict. For example, in 2015, Anglesey Aquaculture (Wales) ceased production of European sea bass as their market value could not compete with that of overseas imports (e.g. see https://seafish.org/aquaculture-profiles/profiles/sea-bass/). Britain's departure from the EU is a cause of concern to some mariculturists within the District as it could potentially impact their trade, access to European markets and matching of European regulations for imports. This is particularly pertinent to the shellfish industry where product, due to its short shelf life, requires rapid transport between supplier and consumer.

Small-scale macroalgal culture requires comparatively little capital investment, which makes it a more accessible potential livelihood than other forms of mariculture (Grebe *et al.,* 2019). However the economic viability of macroalgae farming depends substantially on market issues: market development is required in Europe generally, and access to buyers and appropriate markets is a key consideration when developing these operations (Grebe *et al.,* 2019).

	Action	**Timeframe**
B3	Manage plots within the Waddeton Order on the Dart to allow for shellfishers to trial mariculture or diversify from other fishing activities.	Annually
B4	Review the Waddeton Order area for shellfisheries and consider its future use and potential	2021-2022
B5	To continue to engage with the National Aquaculture Commons Issues Group to provide information help open potential niche markets to D&S IFCA mariculturists.	Annually

5.10 Macroalgae-specific Considerations

The logistics of establishing, servicing and harvesting from mariculture farms can be complex and expensive; this is particularly true for macroalgae, which has relatively low value per tonne, and management of the product requires specific skills. The English Aquaculture Strategy has highlighted that, if this subsector is to expand, it "will need either dedicated or suitably shared facilities to moor service vessels, land product and conduct any primary processing e.g. washing and drying, etc upon landing.

The UK has a highly valuable macroalgae expertise base and an ability to scale up growth (in terms of optimising productivity and lowering costs associated with growth, harvesting and productivity). However, AB-SIG (2013) highlight that "continuity of funding is essential to maintain this advantage: both R&D funds to attract and retain academic excellence, and resources to provide continuity and expansion of the support network that facilitate successful project development between academia and industry, will be essential if the UK is to establish a globally competitive algal commercial sector".

5.11 Export Regulations

English mariculture businesses must comply with specific requirements for export of their product. These are outlined in the Regulatory Framework (Annex 2) and the most up-to-date requirements are available at https://www.gov.uk/guidance/export-live-fish-and-shellfish-for-aquaculture-and-ornamental. The guidance outlined below relates specifically to export of live fish, shellfish, and crustaceans for any purpose except direct human consumption.

Export to the EU

Specific requirements are outlined in Annex 2, though it is important to note here that the EU Commission has indicated that un-depurated Live Bivalve Molluscs (LBMs) from Class B waters cannot be imported from Great Britain into the EU for the purpose of depuration (correct as of March 2021). This affects both wild-harvested LBMs and those from aquaculture. The FHI are unable to certify for these consignments until this situation is resolved. Defra is continuing to look for a solution to allow exports of wild-harvested LBMs to the EU to resume.

LBMs from Aquaculture Production Businesses (APBs), which are intended to go for further farming / on-growing in the EU, must be accompanied by a specific Export Health Certificate available from the FHI. LBMs exported for farming should be unaffected by the current trade restrictions imposed by the EU on LBMs exported for purification in the EU. However, the Government strongly advises that exporters obtain written confirmation that the Border Control Post in the importing country that the consignment will be accepted before starting the export.

Export to non-EU destinations

These are covered in detail in Annex 2, and at https://www.gov.uk/guidance/export-live-fish-and-shellfish-for-aquaculture-and-ornamental.

6. Benefits of Mariculture

Mariculture within D&S IFCA's District could provide a wealth of ecological benefits and ecosystem services, including a sustainable food resource for human consumption. For example, compared to other animal products, fish generally have among the lowest greenhouse gas emissions per gram of edible protein, and the greenhouse gas emissions and water use associated with bivalve mollusc mariculture is especially low (e.g. Hilborn et al., 2018). However, the overall sustainability in terms of greenhouse gas emissions and water use depends on the food sources used and the energy requirements of the activity, and some researchers have called into question the overall importance of mariculture-derived products for improving food security (Belton et al., 2020), particularly as nearshore finfish farming is likely to focus on producing relatively expensive products. By contrast, freshwater aquaculture, which often focuses on lower-trophic level fish that are less expensive to produce and buy, is likely to continue to supply the majority of the world's farmed fish (Belton et al., 2020), particularly in developing countries.

Mariculture, when managed responsibly, can have a positive effect on local ecosystems (Neori *et al*., 2007). For example, birds may be attracted to certain mariculture sites for feeding (CBD Secretariat, 2004; Clavelle et al., 2019), and artificial reefs and infrastructure can act as fish aggregating devices (FADs) and de facto MPAs (by excluding fishing effort and other disturbances) and thereby enhance biodiversity. These FAD and MPA effects could increase capture fisheries potential either through targeting fish aggregations or via spillover effects from de facto MPAs; however, the strength of these effects requires more research (CBD Secretariat, 2004; Clavelle et al., 2019), particularly because fish aggregations may attract predators (which may damage farm infrastructure, be trapped as bycatch, or deplete fish populations) or allow overfishing through increase catch per unit effort.

Offshore mussel farms within the District have the potential to be nursery grounds for many fish species and create areas of increased biodiversity (Sheehan *et al*., 2019). Commercially exploited species like edible crab can be found on the mussel ropes within Lyme Bay (Sheehan et al., 2019) and there is anecdotal evidence provided by Devon sea anglers and mariculturists that oyster trestles attract large aggregations of some fish species that are highly regarded by anglers. Algal farms are less studied but are potentially able to provide similar secondary ecosystem functions to that of rope grown bivalves (McHugh, 2003; Peteiro, 2018).

Some mariculture practices, particularly 'closed loop' practices that do not depend on wild harvest of seed or brood stock, may be considered to be more sustainable than wild harvest of sea fisheries resources. Pacific oyster faming relies on infertile triploid stock so must import the seed from special rearing facilities (Nell, 2002). Rope grown long line mussel passively collects seed from reared stock, with seed settling on specially designed ropes placed in close proximity to the adult mussel lines. Indeed, gamete dispersal from farmed species like mussels and other shellfish which are grown in open systems can help restock public beds by increasing the available abundance of viable larvae within the water column. Pacific oysters farmed via mariculture should not contribute to wild Pacific oyster populations due to the use of infertile triploid stock (Nell, 2002). However, there are some concerns surrounding the potential for reversion of these oysters to the fertile diploid state (Herbert *et al.,* 2016) (see below for more information).

Caged finfish farming is a mariculture industry that is not yet present in the District. In the case of salmonids, this is likely due to preferential conditions for salmonid growth in cooler waters at higher latitudes (Fenkes *et al.,* 2016). D&S IFCA is unaware of any proposed farms within the District. Salmon farms remain the highest grossing mariculture venture in the UK, their growth in the District could bring increased investment, creation of jobs (primarily in fish processing, which is likely to be increasingly automated) and increased food production (though the product is relatively expensive). Like bivalve farms, salmonid farms do not require wild stocks for the supply of sprat for future grow out. Instead, healthy brood stock are selected for breeding and the reproduction process is contained within a closed system (Gjedrem *et al.,* 2012). This means that larval dispersal to the water column is prevented, helping to limit mixing of reared and wild stocks. However, limits to fish physiology and susceptibility of exposed infrastructure to weather events, present challenges for the success of sea pens or cages for finfish mariculture within the District.

Bivalve mollusc mariculture can sequester and fix large amounts of dissolved carbon from the water column: Ahmed et al. (2016) estimated that 16.1 million tons of molluscs could sequester between 0.97–1.93 million tonnes of 'blue' carbon annually. Macroalgal farming has similar potential to sequester carbon and could provide additional benefits in terms of reducing fossil fuel consumption if converted to biofuels (Chung et al., 2011). The sequestration potential for both shellfish and algae are therefore highly relevant to the current global and national drive towards a carbon neutral society. However, whether this carbon is actually sequestered or released back into the environment depends on the fate of the harvested product (Augyte et al., 2017). Offshore installations like rope grown mussel farms also have the potential to provide coastal defence services, absorbing wave energy and potentially decreasing coastal erosion (Plew et al., 2005).

Both bivalve and algae mariculture can improve water quality and clarity, including by removing excessive nutrients from the water column (Gentry et al., 2019). This is true of both single-species mariculture in natural systems, and integrated multi-trophic aquaculture systems. However, the scale of mariculture required to achieve these benefits is likely to be quite large (Gentry et al., 2019).

Coastal fishing communities have suffered economically due to significant declines in the capture fishing industry and increases in fuel prices (Pinder 2003, Abernethy *et al*., 2010). Mariculture can provide both employment and an important cultural link to the sea for former fishers who wish to retain their way of life, diversify into more artisanal fisheries, or provide additional employment to fishers who wish to supplement their income (Reed *et al*., 2013). Mariculture can also support jobs indirectly in supply chains (processors, support vessels, logistical staff, etc.), and can provide economic supports for harbours, ports and other infrastructure used by both mariculture and fisheries; this support is especially important given the seasonal nature of wild-capture fisheries (Clavelle et al., 2019). Importantly, mariculture has the potential to improve national resource security through the creation of sustainable food and other products (biofuel from algae for example).

7. External Costs of Mariculture

There are a range of costs and impacts associated with mariculture that tend to be borne by the environment or by other users of the sea. These are outlined below, and the most up to date available evidence on these costs and impacts will be used by D&S IFCA when considering new mariculture developments in the District, in the context of site-specific considerations and the nature of the proposed activity.

External Costs: Ecosystem Impacts

Mariculture can modify, degrade, or destroy habitat, disrupt food webs, deplete natural seedstock, transmit disease, reduce genetic variability, and otherwise affect wild fish populations by increased demand for forage fish as feed products (CBD Secretariat, 2004). Many known examples of negative impacts of mariculture are from countries around the world, but it is important to note that the environmental impacts of mariculture are not uniform. This is in part because of different regional production patterns and techniques, ecosystem productivity and cultured species, but also because of large differences between countries in the rate of growth and development of aquaculture, and the level of regulation, control and monitoring procedures. Sustainable mariculture management seeks to limit the environmental impacts, often because these are important economic issues (e.g. stocking densities, feed use and disease), are often required by regulations or negatively influence public perception of mariculture (Clavelle et al., 2019). More UK-specific research is required regarding the environmental impacts of mariculture, and their mitigation options.

The food source used to produce biomass is an important determinant of the environmental effects of each production method, which in turn depends largely on culture method and species. Those that rely on photosynthesis or extraction of nutrients from the water column (e.g. macroalgae and mollusc farming) are generally more efficient and tend to have fewer negative impacts on biodiversity than those that derive energy from feeds supplied by growers or wild-capture fisheries (CBD Secretariat, 2004). Indeed, the largest negative impacts of mariculture tend to result from high-input/high-output intensive systems (Belton et al., 2020). These impacts can include the discharge of suspended solids; the nutrient and organic enrichment of recipient waters resulting in the build-up of anoxic (oxygen-depleted) sediments; changes in benthic communities and eutrophication; the release of antibiotics and pharmaceuticals; the introduction of diseases and escapees to the ecosystem; the introduction (deliberate or accidental) of alien species; and impacts on wild species (CBD Secretariat, 2004). However, low-input systems are not without their own drawbacks, as outlined below.

Overall, macroalgal mariculture appears to have limited negative environmental impacts (though may still cause spatial conflicts, outline below for mariculture operations in general). Visch et al. (2020) found that a Swedish seaweed farm provided habitat to mobile fish species and had a positive effect on benthic infauna. No changes were observed in benthic oxygen flux, dissolved nutrient concentrations, and benthic mobile fauna between farm and control sites, though substantial shading from the seaweed was observed at the peak of the biomass just before harvest. Shading impacts may also be expected from other mid-water or surface-based forms of mariculture (e.g. shellfish rafts or fish cages). Benthic communities that are sensitive to change (e.g. seagrass meadows), are those more likely to be affected by shading, though an assessment of the impact of an 18 ha. kelp farm showed no effect on the seagrass (*Zostera marina*) biomass underneath the farm (Walls et al., 2017). Since the peak of the biomass is during a relatively short period in the last phase of the growing season, shading by a seaweed farm may have limited impact on benthic communities. However, Campbell et al. (2019) have highlighted that “whilst current small-scale cultivation projects are considered ‘low risk’, an expansion of the industry that includes ‘large-scale’ cultivation will necessitate a more complete understanding of the scale dependent changes in order to balance environmental risks with the benefits that seaweed cultivation projects can offer.”. However, it has still been recommended to avoid farm placement in well-vegetated areas and habitats that are protected under the WFD is still recommended (Campbell et al., 2019).

The remainder of this section relates to specific ecosystem impacts associated with mariculture.

Invasive Non-native Species, Escapees, Parasites & Disease

Globally, mariculture is considered to be a major potential source of introductions of non-native species to marine ecosystems. Feral populations of non-native species may establish following escapes of species that are being farmed outside of their native range. In the UK, and Europe generally, Pacific oysters (*M. gigas*) are now regarded as potentially representing a serious invasive threat but were – and still are – introduced to many coastal waters in mariculture developments. It was initially expected that *M. gigas* would only spread in a very limited way because their development is temperature-sensitive, and UK waters tend to have few days of temperatures in the preferred range (around 15–25 °C), which is required for conditioning, larvae survival and settlement of spat (Child and Laing 1998; Syvret et al. 2008). However, predicted increases in seawater temperature associated with climate change may increase and accelerate its spread (Rinde et al. 2016; Robins et al. 2017). Steps have therefore been taken to further limit the invasive potential of cultured oysters. Mariculture of Pacific oyster relies on obtaining seed from hatcheries. The seed are either diploid (two sets of chromosomes and fertile) or triploid (treated to become sterile). Diploid oysters were initially farmed but the industry have moved towards triploid oysters, which are believed not to spawn in UK waters (limiting their invasive potential) and to have a better meat yield. However, under some circumstances (including abnormally warm conditions, and with an ageing stock), triploid oysters are known to revert back to the diploid state and therefore are no longer sterile (Herbert *et al.*, 2016). The two are morphologically similar and not easy to distinguish (Nell 2002). Wild settlement of Pacific oyster is not limited to the vicinity of mariculture sites: isolated outbreaks are known to have occurred in areas more than 50 km away from the nearest farm, suggesting that other pathways of introduction may exist. D&S IFCA is not aware of evidence to suggest that larval drift is responsible for these longer-distance introductions; transportation of adults or entrained larvae with vessel traffic and in ballast water is deemed to be more likely (Herbert *et al.,* 2012).

Clusters of Pacific oyster and native oyster appear to support similar species assemblages and diversity when found on hard substrates (e.g. rock; Zwerschke et al. 2016). The evidence therefore suggests that impacts of Pacific oyster on biodiversity may not relate directly to changes in local species composition. Therefore, if Pacific oysters settle in areas that previously supported large native oyster populations, they may support the local biodiversity and provision of ecosystem services. However, it is still unclear whether this situation changes in different habitat types or in dense or mature oyster beds (for example, as a result of larger differences in morphology and life history traits between adults of these oyster species (Mann 1979; Herbert et al. 2016; Green 2017; Nielsen et al. 2017). There are also concerns that Pacific oyster could displace native oyster, which are already declining in the UK (Laugen et al. 2015; Zwerschke et al., 2017).

A more significant concern is that Pacific oysters may modify habitats over wide areas. This is a particular concern in protected sites that have designated features which are sensitive to such transformation. In Europe, large areas of mudflat and rocky shore have been transformed to oyster reef, and small intertidal areas of *Sabellaria spinulosa*, a reef-building worm, in Kent have been smothered by Pacific oyster. The abundance of *Sabellaria alveolata* has also been limited by Pacific oyster in some parts of Europe (Dubois et al. 2006; Green and Crowe 2013).

Parasites found in farmed populations may escape to wild populations, where they may be harmful. For example, the mollusc pathogen *Bonamia ostreae* was introduced to Europe with infected flat oyster spat from the USA in the 1970s. The disease spread rapidly via infected oysters in the extensive European trade in shellfish spat and juveniles. All of the countries that are affected by this parasite have been unable to eradicate it (OSPAR Commission, 2009). Sea trout (*Salmo trutta* L.) and Atlantic salmon (*S. salar* L.) are hosts for sea lice. The transfer of parasites between farmed and wild fish is a cause for concern (Boxaspen, 2006). In Europe, farmed Atlantic salmon now dramatically outnumber wild Atlantic salmon (Porter, 2003). Salmon cages, where fish are kept at high densities, provide an ideal environment for the proliferation and spread of sea lice. Low stocking densities and fallowing of cages can reduce sea louse numbers.

Disease transmission can occur between caged and wild fish and escaped farmed fish can transfer disease to other culture stocks and wild populations over a wide geographic area. It may be that diseases of wild origin attain a more virulent state in the farm environment, before re-release to the wild (OSPAR Commission, 2009). Cultured salmonids have been known to spread diseases including infectious pancreatic necrosis (IPN), infectious salmon anaemia (ISA), viral haemorrhagic septicaemia (VHS) and furunculosis. The DIPNET project published a comprehensive review of disease interactions and pathogen exchange between farmed and wild finfish and shellfish in Europe in 2007 (DIPNET, 2007). Live fish/shellfish movements, which are common in mariculture, are known to be the greatest risk for introduction and transmission of disease.

Mariculture has the potential to provide an almost continuous supply of escapees into the natural environment, through day-to-day operations including stocking, grading and disease treatment. Occasional mass releases also occur due to infrastructure damage caused by storms, predators, or construction failure (OSPAR Commission, 2009). Kavanagh et al. (2007) reported that globally, 10.2 million farmed salmonids escaped from open net cages between 2002 and 2006. In 2020, approximately 50,000 salmon escaped and an additional 30,000 died when a fish farm in Argyll, Scotland, broke free from its moorings during Storm Ellen. By October 2020, some of these escapees had been found in three rivers in Cumbria, England (150 miles away).

Farmed salmon are selectively bred for characteristics such as rapid growth, fat content and resistance to disease, and are therefore genetically distinct from their wild counterparts. They also tend to lack the genetic variability for adaptability and long-term survival and have a reduced reproductive capacity in the wild. Despite this, escaped farm salmon do breed successfully and hybridise with wild fish (OSPAR Commission, 2009), thereby potentially changing the genetic make-up, fitness, and life-history characteristics (e.g., age and timing of maturity and spawning) of wild populations. There is relatively low interbreeding between wild salmon stocks from different rivers, which return to their natal river to breed. Farmed salmon have reduced homing abilities and the interbreeding of wild salmon with escaped farmed salmon that have no attachment to a particular river can reduce local adaptation, impacting the viability and character of the stock with the result that the hybrid offspring have a lower survival rate (OSPAR Commission, 2009). Indirect genetic effects can also occur if diseases from farms cause reductions in wild populations (Davenport et al., 2003).

Species Hybridisation

This issue is pertinent to the South West as there is mixing and hybridisation of two species of blue mussel: the native *Mytilus edulis* and non-native *M. galloprovincialis*. For the majority of England *M. edulis i*s the dominant species with low to negligible spatial competition with other blue mussel species. In the South West *M. galloprovincialis* is also established. *M. edulis* and *M. galloprovincialis*, both occupy similar environmental niches and can hybridise with one another to produce viable offspring. These hybrids have only been found in areas of high aquaculture activity where the two species mix (Michalek *et al*., 2016).

The impacts of hybridisation of differing mussel species even within UK waters although largely unknown can be negative. One such example, *M. trossulus* is a non-native species of mussel present in parts of in Scotland that is currently having a negative economic impact on local shellfish farms due to hybridisation with stock mussels. Unlike *M. edulis, M. trossulus* have very thin and brittle shells making them unsuitable for commercial sale. They have manged to successfully hybridise with other *Mytilus* species producing offspring with the same traits. The difficulty in being able to tell either species apart means that mariculturists may unknowingly produce large volumes of the unsellable *M. trossulus* alongside *M. edulis* (Michalek *et al*., 2016, Vendrami *et al.,* 2020). The long-term effects of hybridisation of *M. galloprovincialis* with *M. edulis* remain to be seen, and though they may not be as potentially negative as the case seen in Scotland's with *M. trossulus*, decreased intra reproductive fitness as is sometimes seen in hybridisation of distinct populations in other species (Vendrami *et al.,* 2020).

Hybridisation is also occurring between the Portuguese oyster (*Croassostrea angulata*) and the Pacific oyster (*M. gigas*) between France and Portugal (OSPAR Commission, 2009). Another example of the negative effects of mixing of distinct populations is in farmed salmon. Escape and accidental release of reared salmon has resulted in global instances of interbreeding of reared stock with wild stock. The resulting wild/reared hybrids tend to have decreased reproductive fitness which as a result threatens the stability of wild populations. (Sylvester *et al.,* 2018). Similar consequences should be considered for wild finfish populations in the District if finfish mariculture becomes established.

Maintenance and Harvesting Impacts

Though some mariculture activities can support feeding birds, birds (and other predators) may avoid some areas of increased human activity (e.g. human presence, boat traffic). In addition, mollusc harvesting (of product or seed stock, especially of intertidally cultivated organisms on or in the substrate) can be invasive, causing disturbance to sediments and their associated fauna, and disturbance to local bird populations (OSPAR Commission, 2009). In 1990 and 1991, overexploitation of Wadden Sea mussel seed stocks caused depletion of the entire mussel stock, resulting in eider duck mortalities, and reducing breeding success of oystercatchers (OSPAR Commission, 2009; Kaiser et al., 1998).

The maintenance and harvesting of suspended and trestle grown bivalves has little direct impact (OSPAR Commission, 2009). However, harvesting of intertidal species cultivated on or in the substratum requires various means of mechanical extraction such as the use of tractors and suctions dredges for cockle extraction which removes the entire upper sediment layer and infauna (Kaiser and Beadman, 2002). Access routes for tractors and other vehicles may also damage the foreshore (OSPAR Commission, 2009).

Benthic Environment

Sediments under large intensive shellfish farms in areas with limited tidal exchange can become anoxic, giving rise to hydrogen sulphide production and a decrease in local biodiversity (OSPAR Commission, 2009). Psuedofaeces produced by bivalve molluscs are nutrient-rich, changing the underlying sediment composition. The associated infrastructure may also become fouled with algae, increasing organic enrichment when this algae dies back seasonally. Though molluscs remove dissolved nutrients from the water, the balance between this and the particulate organic matter they produce is different from the balance that exists in their absence, which can negatively impact the benthos. Impacts are considered to be lower under longlines than under rafts as the amount of pseudofaeces falling from longlines is spread over a larger area (OSPAR Commission, 2009). However, increased primary production around the infrastructure can increase the numbers of pelagic fish species.

Organic enrichment is also a serious issue with finfish mariculture. Uneaten food pellets, fish wastes and dead individuals settle out in the sediments in the vicinity of fish cages. The area of the seabed affected depends largely on the area and stocking density of the farm, the currents and local tidal conditions, and depth of water beneath the cages. This results in an inner impact zone receiving all types of waste, and an outer zone that is enriched just by fish waste. Loadings beneath farms can be high but tend to be very localised. As with molluscan mariculture, sediments can become anoxic and outgas hydrogen sulphide and methane and produce ammonia. Under high nutrient loadings there may be a loss of sensitive species.

These systems can be managed to avoid organic over-enrichment. In cage mariculture, uneaten feed is a primary source of organic loads. As feed can constitute 40% of the running costs of a farm, it is in the mariculturists interest to reduce waste. Feeding regimes are important determinants of the amount of feed lost. Other management options relate to site selection, monitoring of fish deaths, cage movements and fallowing sites (OSPAR Commission, 2009).

Artificial Chemical Inputs

The amount of chemicals used in shellfish mariculture is negligible (OSPAR Commission, 2009). In finfish farming, antibacterial, antifungal and antiparasitic treatments (for example, against sea lice) are the most commonly used medicinal treatments. The increased use of vaccines has significantly reduced the use of antibiotics in mariculture, while salmon farms are increasingly using cleaner fish (wrasse and lumpsuckers) as biocontrol for sea lice. The use of cleaner fish poses an ecological conundrum when these fish are sourced from the wild, though the salmon farm industry is making progress with farmed cleaner fish and is thought to be reducing reliance on wild populations. Feed is also a potential source of other additives and contaminants. Persistent compounds, such as PCBs, have been detected in the fish oil/fish meal used in feed. OSPAR Commission (2009) have published information on the active ingredients of chemicals used in finfish mariculture, method of use and quantities used in Ireland, Norway, and United Kingdom, in addition to environmental toxicity information of the most commonly used chemicals.

Managing Environmental Impacts

The following information has been derived from OSPAR Commission (2009). The environmental impacts of mariculture within the EU countries of OSPAR are regulated and managed at a European level by several Directives. These include the Dangerous Substance Directive (Council Directive No. 2006/11/EC), the Quality of Shellfish Growing Waters Directive (Council Directive No. 2006/113/EC), the Environmental Impact Assessment Directive, the Strategic Environmental Assessment Directive, Water Framework Directive

(Commission Directive No. 2000/60/EC), the EC Nitrates directive (Council Directive No. 91/676/EEC), the Wild Birds Directive, the Species and Habitat Directive. As of 1 August 2008, Council Directive No. 2006/88/EC (on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals) governs all aspects of cultured fish welfare within the EU and retained EU legislation.

In order to mitigate against the environmental impacts of mariculture, a concerted action among public and private sectors is required. Several initiatives and advances in environmental management are being employed. On an individual farm basis, initiatives and mitigation against environmental impacts may include:

- Increased use of fallowing (to reduce nutrient and pathogen loadings)
- Improved cage design
- Feed improvements to reduce ecological impacts of food sources, improve efficiency of feed uptake by fish, and reduce the likelihood of feed sinking through the farm before being eaten
- Increased efficiency in use of medications and use of vaccines and in-feed treatment rather than bath treatments to reduce dispersal into environment.
- Reduced applications of antifoulants and increased use of eco-friendly antifouling coatings and products
- Increased use of integrated mariculture practices (IMTA) or co-location of complementary culturing activities (e.g. seaweed and shellfish culture) can help reduce nutrient outputs of caged farms and provide an additional product (see below)
- Intelligent siting of farms relative to tidal conditions, currents, and water depth.

More broadly, regional management approaches are also important.

- Single bay management plans to coordinate fallowing and reduce overall inputs of chemo-therapeutants
- Implementation of integrated coastal management tools may help predict the environmental impacts of mariculture activities
- Effective enforcement of regulations and establishment of permanent monitoring programmes, both to evaluate external factors affecting mariculture as well as impacts of mariculture in the environment.
- Coordination between official institutions and farmer groups and the integration of codes of conduct and regulations
- Training in modern, environmentally sound techniques for farmers and more effective dissemination of technological advances amongst farmers.

Some impacts from high-input mariculture practices may be reduced or offset by practicing alternative forms of mariculture, including a technique known as Integrated Multi-Trophic Aquaculture (IMTA). IMTA is the integrated culturing of fed species, (e.g. finfish) with inorganic extractive species (e.g. seaweeds), and organic extractive species such as suspension-and deposit-feeders (Troell et al., 2009). In this system, not only are two marketable products raised with approximately the same spatial footprint, but the extractive, filter-feeding species can also filter some of the excess nutrients associated with the fed species from the water. Alternatively, Recirculating Aquaculture Systems (RAS) remove the fish production from the marine environment to an almost completely closed system in which the water is purified and reused, allowing for wastes to be removed. This provides a fully controlled environment for the fish, but is very energy- and water-consuming, and still requires high quality feed input.

External costs: Social and Economic Impacts

D&S IFCA must seek to balance the different needs of persons engaged in the exploitation of sea fisheries resources in the District. D&S IFCA must therefore be mindful of the uncertain social and economic implications of mariculture for fishers in the District. While the ecological implications of mariculture for wild capture fisheries are generally well-studied, the social and economic implications have been less widely investigated by the wider research community (Clavelle *et al.,* 2019). Mariculture installations and businesses may be socially and economically detrimental to wild capture fishers by excluding them from traditional fishing grounds, intensifying price competition or altering the market for seafood products (Aguilar-Manjarrez et al., 2017; Akyol and Ertosluk, 2010; Sanchez-Jerez et al., 2016).

One of the most contentious issues in conversations around mariculture development is perceived or actual competition for space with commercial and recreational fishers (Sivas and Caldwell, 2008). Some research has highlighted that mariculture installations in other countries have reduced the extent of available fishing grounds, disturbed navigation and altered landings of commercial fishers (Aguilar-Manjarrez et al., 2017; Akyol and Ertosluk, 2010; Sanchez-Jerez et al., 2016). This may affect the quality of life of nearby fishing communities, particularly those that are limited to inshore coastal areas by the size and power of their vessels, or the distribution of their target catch. It is not always easy, or indeed possible, for fishers to change their fishing locations or methods; diversification can be an expensive and complex process that requires purchasing of new gear and updating skill sets.

The Explore Marine Plans website (https://explore-marine-plans.marineservices.org.uk/) supports the implementation of the South and South West Marine Plans, which relate to the waters of D&S IFCA's District. This website maps areas that have been deemed suitable for a range of mariculture activities; however, the identified areas do not account for the presence or activities of existing users of the sea (particularly inshore fishers operating vessels under 12 m in length), or of essential fish habitats that support fish and fisheries. The development of mariculture in these areas may therefore conflict with the space use requirements of other legitimate users of the sea. Inshore areas within the district are primarily fished by small scale fisheries using pots, nets and operating towed gear. Many of those prosecuting these fisheries have historic, community and economic ties to the specific grounds they fish, and may see mariculture developments on or near their fishing grounds as a threat to their business and way of life. This is especially the case for fishers operating mobile demersal gear; much of the inshore waters in the D&S IFCA's District are closed to demersal fishing gear (43% in the southern part of the District) and therefore there is a strong desire by this portion of the fleet to allow their activities to continue in these open areas. D&S IFCA aims to improve the applicability of the Marine Plans and the siting of mariculture installations by carrying out thorough mapping of the inshore fishing activities and essential fish habitat in the District. D&S IFCA will seek to employ a dedicated GIS Officer to deliver this mapping, and is identifying further evidence gaps relevant to inshore fisheries through specific Fisheries Research and Management Plans.

Products from wild capture fisheries and mariculture may compete in the marketplace, affecting consumer choices and market prices. For each fishery, the extent to which this occurs will depend on a combination of factors, from the species and technologies involved to the degree to which consumers deem the products to substitutable for one another, fishery management measures in place and product marketing. Where farmed and wild products are more substitutable, mariculture can reduce demand for and capture of wild fish (Asche *et al.,* 2005; Castillo-Manzano *et al.,* 2014; Bjørndal and Guillen, 2017). Product competition also depends largely on consumer preferences. Consumer preference for different production methods appears to be more distinct for high-value species (Reynier and Bayramoglu, 2016), and studies in the EU and Canada have shown that when all else is equal, consumers express a preference for wild caught versus farmed seafood (Murray *et al.,* 2017; Claret *et al.,* 2012). However, as highlighted above, consumer acceptance of farmed seafood appears to be increasing, and eco-labelled farmed products appear to be preferred over eco-labelled wild-caught products, suggesting that consumers environmental concerns (allayed by eco-labelling) may be a primary determinant of preferences (Ankamah-Yeboah *et al.,* 2016; Bronnmann and Asche, 2017). Indeed, in a 2018 survey, 70% of UK adults who eat fish claimed that sustainability is important to their choice of fish (Seafish, 2019). Mariculturists may therefore be interested in achieving certification, for example via the Aquaculture Stewardship Council, which has developed standards for a range of farmed species. However, it is also important to note that country of origin and freshness appear to be more important than production methods in determining consumer preferences overall (Claret *et al.,* 2012).

	Action	Timeframe
A1	Provide up to date maps of all current mariculture fixtures within the District: for public information and to clearly identify areas where other forms of marine development would not be encouraged by D&S IFCA. This information will be updated on D&S IFCA's website and used where appropriate in response to enquiries and consultations on marine developments.	2021–2022; following appointment of GIS Officer (A2)
A2	Highlight, through the production of maps, spatial zones where the existing use is low and the potential for future mariculture developments may exist. Fulfilment of this action will require the contracting of a GIS Officer based with D&S IFCA, who will map existing activities and other relevant information such as spawning and breeding grounds where possible, in order to also identify areas where other forms of marine development would not be encouraged by D&S IFCA.	2021–2022
B1	Review and respond to all relevant marine licence applications and with regard to mariculture, to include: information on existing use of area consultations, ecosystem impacts, social and economic factors.	Regularly and as and when required
B3	Manage plots within the Waddeton Order on the Dart to allow for shellfishers to trial mariculture or diversify from other fishing activities.	Annually
B4	Review the Waddeton Order area for shellfisheries and consider its future use and potential	March 2021
B5	To continue to engage with the National Aquaculture Commons Issues Group to help open potential niche markets to D&S IFCA mariculturists.	Annually
D1	Continue dialogue with current and prospective mariculturists within the District in order to keep abreast of industry concerns and progress and understand how mariculture interests can be furthered.	Ongoing through regular meetings and updates
D2	Publicise online Mariculture Resource Pack, containing resources that will be beneficial for existing and future mariculturists.	2021-2022 and updated regularly thereafter
D3	Publish news items and relevant literature online to help keep mariculturists ahead and informed of relevant mariculture news. Build relevant information into Mariculture Resource Pack.	Ongoing, as and when information becomes available
D4	Help to disseminate information about biosecurity measures in mariculture sites, including Defra's upcoming review on Pacific oyster impacts. Build relevant information into Mariculture Resource Pack.	Ongoing, as and when information becomes available
D5	Continue dialogue with mariculturists and other users of the sea that may operate near to mariculture sites, using D&S IFCA's published maps of new and existing mariculture sites to help reduce spatial conflict.	Ongoing
D6	Use D&S IFCA's published maps and other relevant literature resources as a basis for preventing unwarranted interference in mariculture activities by those involved in projects to remove or eradicate Pacific oysters.	Ongoing

Annex 1: All Actions.

This Mariculture Strategy represents the first steps of a long journey in developing a sustainable mariculture industry in the D&S IFCA's District. Overall, successful future development of sustainable mariculture will require close collaboration between stakeholders across the supply chain, as well as scientists and regulators. For D&S IFCA to continue on this journey will require the pursuit of a set of key actions, outlined throughout the Strategy and summarised below. It is hoped that these actions will enable D&S IFCA to support a growing mariculture industry. Additional actions have been added in the Resource Development table relating to the development of a Taw Torridge Mussel Management Strategy in 2021-2022 and the potential for Mariculture Parks in the D&S IFCA's District.

The Strategy will be reviewed regularly to reflect the progress made and outline changes in costs and benefits in this dynamic system, to assess progress against key actions and to identify where new actions may be required in order to meet the aims of the Strategy, or to account for changes in the legislative framework arising, for example, through EU Exit..

A1–A4: Resource development

	Action	Timeframe
A1	Provide up to date maps of all current mariculture fixtures within the District: for public information and to clearly identify areas where other forms of marine development would not be encouraged by D&S IFCA. This information will be updated on D&S IFCA's website and used where appropriate in response to enquiries and consultations on marine developments.	2021–2022; following appointment of GIS Officer (A2)
A2	Highlight, through the production of maps, spatial zones where the existing use is low and the potential for future mariculture developments may exist. Fulfilment of this action will require the contracting of a GIS Officer based with D&S IFCA, who will map existing activities and other relevant information such as spawning and breeding grounds where possible, in order to also identify areas where other forms of marine development would not be encouraged by D&S IFCA.	2021–2022
A3	Continue collecting up to date statistics on mariculture production within the District.	Ongoing
A4	Produce a comprehensive guide and online resource library (Mariculture Resource Pack) for new and existing mariculturists who are looking for development opportunities within the District. This pack will include the outline Regulatory Framework that applies to mariculture operators.	2021–2022; following appointment of GIS Officer (A2)
A5	In 2021-2020 D&S IFCA will develop a Taw Torridge Mussel Fishery Management Strategy which will identify a programme of actions for the development of the mussel fishery. This ill be adopted in this Mariculture Strategy.	2021-2022
A6	D&S IFCA will liaise with stakeholders and agencies to support Mariculture Parks where appropriate in its District	2021-2022

B1–B5: Activity management

	Action	Timeframe
B1	Review and respond to all relevant marine licence applications and consultations with regard to mariculture, to include: information on existing use of area, ecosystem impacts, social and economic factors.	Regularly and as and when required
B2	Submit recommendation for D&S IFCA's Byelaw and Permitting Sub-Committee for potential management of mobile gear activities to protect mariculture sites within the District.	2021-2022
B3	Manage plots within the Waddeton Order on the Dart to allow for shellfishers to trial mariculture or diversify from other fishing activities.	Annually
B4	Review the Waddeton Order area for shellfisheries and consider its future use and potential	2021-2022
B5	To continue to engage with the National Aquaculture Commons Issues Group to help open potential niche markets to D&S IFCA mariculturists.	Annually

C1–C4: Product safety and water quality

	Action	Timeframe
C1	Collaborate with agencies that are involved with projects that seek improvements to upstream management of agriculture and wastewater discharges e.g. AMP 5, Catchment sensitive farming, text alerts	Ongoing continues liaison as project arise
C2	Liaise with the relevant agencies involved with the regulation of water quality to aid reporting of incidents of poor water quality that have affected shellfish businesses and production.	Ongoing
C3	Support the consideration of alternative testing and monitoring procedures to improve food safety whilst reducing the current limitations on shellfish productions.	As and when new methodologies for testing are developed
C4	Continue liaising with HAB sensing organisations like S3 - EUROHAB to address and quantify the impact of HABs on the District's mariculture.	Ongoing until end of project - 2022

D1–D10: Engagement

	Action	Timeframe
D1	Continue dialogue with current and prospective mariculturists within the District in order to keep abreast of industry concerns and progress and understand how mariculture interests can be furthered.	Ongoing through regular meetings and updates
D2	Publicise online Mariculture Resource Pack, containing resources that will be beneficial for existing and future mariculturists.	2021-2022 and updated regularly thereafter
D3	Publish news items and relevant literature online to help keep mariculturists ahead and informed of relevant mariculture news. Build relevant information into Mariculture Resource Pack.	Ongoing
D4	Help to disseminate information about biosecurity measures in mariculture sites, including Defra's upcoming review on Pacific oyster impacts. Build relevant information into Mariculture Resource Pack.	Ongoing
D5	Continue dialogue with mariculturists and other users of the sea that may operate near to mariculture sites, using D&S IFCA's published maps of new and existing mariculture sites to help reduce spatial conflict.	Ongoing
D6	Use D&S IFCA's published maps and other relevant literature resources as a basis for preventing unwarranted interference by those involved in projects to remove or eradicate Pacific oysters from areas in some estuaries which are classified for mariculture.	Ongoing
D7	Engage with regulators such as Cefas, FSA, EHO, SAGB and ACIG to provide a conduit on issues and advances in mariculture to mariculturists in the District. Build relevant information into Mariculture Resource Pack and disseminate information to mariculturists.	Ongoing through regular meetings and updates
D8	Review new reports on wild pacific oyster spread and its maintenance, and the potential impacts on MPA features	Ongoing
D9	Liaise with Standing Environment Groups, Harbour authorities and EA on their maintenance works and Pollution Action/contingency plans, and training/simulation incident management Exercises.	Ongoing
D10	Keep abreast of the literature and Government advice regarding the impacts of climate change that could impact the mariculture industry.	Ongoing

Annex 2: Regulatory Framework and Mariculture Resource Pack

A key action for D&S IFCA is to develop an online resource pack that can be used alongside this Mariculture Strategy. D&S IFCA's aim is that this Mariculture Resource Pack will be a useful reference point for current and prospective mariculturists who would like to stay up to date with relevant industry, scientific and regulatory information. This Pack, which will include a Regulatory Framework, should also provide an appropriate set of resources for those seeking to establish or expand mariculture operations in D&S IFCA's District. A tabulated version of the Regulatory Framework, within which mariculturists in the District must operate, is included here for reference, followed by guidance on export regulations.

Regulatory Framework

Listed below are the organisations involved in developing and regulating an Aquaculture Production Business (APB). It is important that each organisation/authority is consulted at the appropriate stage to gain the relevant permissions to proceed with the next phase of development/farming activity. Export regulations follow this table.

Factor	Regulator/Authority	Remit	Contact
Site development	Local Authorities	Planning Permission for land-based fish farms. Consultee for marine based aquaculture developments.	www.gov.uk/find-your-local-council
	Marine Management Organisation (MMO) licensing team	Marine Licence – licencing of all finfish & macroalgae farms, and shellfish farms where exemptions do not apply. Screening if an Environmental Impact Assessment (EIA), or Habitats Risk Assessment (HRA) is required.	www.gov.uk/guidance/make-a-marine-licence-application
	Crown Estate, Duchy of Cornwall, Shellfish orders (or other landowners)	Seabed/foreshore lease – granting of rights for aquaculture development.	www.thecrownestate.co.uk/coastal/aquaculture/working-with-us/
	Natural England	Statutory consultees to planning and licencing authorities	www.gov.uk/government/organisations/natural-england
	Environment Agency (EA)	Statutory consultees to planning and licencing authorities	www.gov.uk/government/organisations/environment-agency
	Centre for Environment, Fisheries & Aquaculture (Cefas)	Environmental Impact Assessment (EIA), or Habitat Regulations Assessment (HRA)	www.cefas.co.uk/
Authorisation to commence farming	Fish Health Inspectorate (FHI)	Authorisation to operate aquaculture production business (APB) Authorisation to import livestock Permitting farming of alien species	Email: fhi@cefas.co.uk www.gov.uk/fish-and-shellfish-farm-authorisation-and-registration

			https://www.gov.uk/guidance/import-or-export-live-fish-and-shellfish www.gov.uk/introduce-or-keep-non-native-fish-and-shellfish
	Environment Agency (EA)	Abstraction & Discharge Licences Fish supplier permitting	Email: enquiries@environment-agency.gov.uk www.gov.uk/environmental-management/water www.gov.uk/permission-to-move-live-fish-to-or-from-a-fishery
Operational authorisations	Local Authorities – Environmental Health Officers (EHO)	Water quality testing	www.gov.uk/find-your-local-council
	Food Standards Agency (FSA)	Classification and administration of shellfish harvesting areas. Biotoxin monitoring.	Email: helpline@foodstandards.gsi.gov.uk www.food.gov.uk/business-industry/farmingfood/fish-shellfish/
Other Parties	Maritime & Coastguard Agency (MCA)	Training and certification of seafarers on maritime health and safety.	www.gov.uk/government/organisations/maritime-and-coastguard-agency
	Devon & Severn IFCA	Fisheries and conservation managers. Powers to create & enforce local fisheries byelaws and permits regulating certain activities.	www.devonandsevernifca.gov.uk
	Gangmasters Labour & Abuse Authority (GLAA)	GLAA licensing scheme regulates businesses who provide workers to the fresh produce supply chain, including shellfish gathering. If you provide workers for shellfish gathering you will need a license.	www.gla.gov.uk
	Animal & Plant Health Agency (APHA)	Applicable only to finfish farming: the APHA issues authorisation to transport live vertebrate animals.	www.gov.uk/farm-animal-welfare-during-transportation

	Veterinary Medicines Directorate (VMD)	Sampling and monitoring of aquaculture premises, in order to protect animal and human health, and the environment. Provide marketing authorisations.	Email: inspections@vmd.defra.gsi.gov.uk www.gov.uk/government/organisations/veterinary-medicines-directorate

Export Regulations

English mariculture businesses must comply with specific requirements for export of their product. These are outlined here, though the most up-to-date requirements are available at https://www.gov.uk/guidance/export-live-fish-and-shellfish-for-aquaculture-and-ornamental. The guidance outlined below relates specifically to export of live fish, shellfish, and crustaceans for any purpose except direct human consumption.

Export to the EU

To export live fish and shellfish to an EU country, the export must be accompanied by an export animal health certificate obtainable from the Fish Health Inspectorate (Cefas). If the FHI is able to grant certification, an inspection of the goods for export will be arranged. The export must be checked and cleared at an appropriate Border Control Post that has been notified of the consignment for export using the TRACES-NT system. The website detailed above also outlines requirements to comply with labelling and HMC customs requirements, and details of appropriate animal welfare and EORI numbers.

In the case of exporting live bivalve molluscs to the EU, these also require an export health certificate and cannot be landed directly into the EU by UK fishing vessels. Live bivalve molluscs (LBMs) such as oysters, mussels, clams, cockles and scallops can continue to be exported to the EU provided that they are suitable for direct human consumption: they must have been harvested from Class A waters or have been depurated (purified) in the UK and have cleared end product testing. The Local Health Authority can provide certificates export health certificates for live bivalve molluscs for direct human consumption.

The EU Commission has indicated that un-depurated LBMs from Class B waters cannot be imported from Great Britain into the EU for the purpose of depuration (correct as of March 2021). This affects both wild-harvested LBMs and those from aquaculture. The FHI are unable to certify for these consignments until this situation is resolved. Defra is continuing to look for a solution to allow exports of wild-harvested LBMs to the EU to resume.

LBMs from Aquaculture production Businesses (APBs), which are intended to go for further farming / on-growing in the EU, must be accompanied by a specific Export Health Certificate: "Model animal health certificate for the import into the European Union of aquaculture animals for farming, relaying, put and take fisheries and open ornamental facilities". This certificate, available from the FHI, is limited to LBMs sourced from aquaculture establishments and does not cover wild sourced molluscs. LBMs exported for farming should be unaffected by the current trade restrictions imposed by the EU on LBMs exported for purification in the EU. However, the Government strongly advise that exporters obtain confirmation, in writing, from the BCP in the importing country that the consignment will be accepted before starting the export. Any decision to export LBMs for this purpose is a commercial decision for you to take as an industry and will be carried out at the exporter's own risk.

Export to non-EU countries or Crown Dependencies

An export animal health certificate may be requirement, which is applied for from the FHI under the same process as for EU exports, including inspections of goods for export before a certificate can be granted. The producer or their customer must find out the animal health certification requirements from the competent authority or official service for aquatic animal health in the destination. In the case of non-EU countries, their embassy in the UK may be contacted for assistance. For Crown Dependencies, the producer must ensure that animal welfare during transport rules are followed. APHA may be contacted for additional information. In all cases, the producer must ensure their consignment meets all requirements for transport and arrival at the destination. The customer or their Agent should be able to confirm these requirements.

Movement to Northern Ireland

This process is similar to that for export to the EU. Full details are available at https://www.gov.uk/guidance/export-live-fish-and-shellfish-for-aquaculture-and-ornamental

References

AB-SIG (2013). *A UK roadmap for algal technologies*. Algal Bioenergy Special Interest Group. Collated for the NERC-TSB Algal Bioenergy-SIG by B. Schlarb-Ridley and B. Parker, Adapt, 75pp.

Abernethy, K.E., Trebilcock, P., Kebede, B., Allison, E.H. and Dulvy, N.K. (2010). Fuelling the decline in UK fishing communities. *ICES J Mar Sci*, 67: 1076–1085.

Aguilar-Manjarrez, J., Soto, D., and Brummett, R. (2017). Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture (No. ACS113536) (p. 395). Rome, Italy: FAO. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=XF2018000446

Ahmed, N., Bunting, S.W., Glaser, M., Flaherty, M.S. and Diana, J.S. (2016). Can greening of aquaculture sequester blue carbon? *Ambio,* 46(4): 468–477.

Ahsan, D.A. and Roth, E. (2010). Farmers' perceived risks and risk management strategies in an emerging mussel aquaculture industry in Denmark. *Marine Resource Economics*, 25(3): 309–323.

Akyol, O., and Ertosluk, O. (2010). Fishing near sea-cage farms along the coast of the Turkish Aegean Sea. *Journal of Applied Ichthyology*, 26: 11–15.

Anderson, D.M., Glibert, P.M. and Burkholder, J.M. (2002). Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*, 25(4): 704–726.

Arzul, I., Renault, T., Lipart, C., Davison, A.J. (2001). Evidence for interspecies transmission of oyster herpesvirus in marine bivalves. *Journal of General Virology*, 82(4): 865–870.

Augyte, S., Yarish, C., Redmond, S. and Kim, J.K. (2017) Cultivation of a morphologically distinct strain of the sugar kelp, *Saccharina latissima forma angustissima*, from coastal Maine, USA, with implications for ecosystem services. *Journal of Applied Phycology* 29(4): 1967–1976.

Austin, A. (2018). *Seafood 2040: A strategic framework for England.* 60pp. Available at: http://faolex.fao.org/docs/pdf/gbr188176.pdf

Bayne, B.L. (1976). The Biology of Mussel Larvae. *In*: B.L. Bayne (*ed.*) *Marine Mussels: Their Ecology and Physiology*. Cambridge, Cambridge University Press, 1: 81–120.

Bayne, B.L. and Worrall, C.M. (1980). Growth and production of *Mytilus edulis* from two populations. *Marine Ecology Progress Series*, 1: 317–328.

Belton, B., Little, D.C., Zhang, W., Edwards, P., Skladany, M. and Thilsted, S.H. (2020). Farming fish in the sea will not nourish the world. *Nature Communications*, 11: 5804.

Boxaspen, K. (2006). A review of the biology and genetics of sea lice. *ICES Journal of Marine Science*, 63: 1304–1316.

Campbell, I., Macleaod, A., Sahlmann, C., Neves, L., Funderud, J., Overland, M., Hughes, A. and Stanley, M. (2019). The environmental risks associated with the development of seaweed farming in Europe-prioritizing key knowledge gaps. *Front. Mar. Sci.*, 6: 107

Capuzzo, E., Mengo, E. and Kennerley, A. (2019). Seaweed farming feasibility within the Dorset and East Devon FLAG area. Report 1 -Potential species, farming methods, end uses and benefits. Cefas Contract C7747, European Maritime and Fisheries Fund (EMFF) grant number ENG2805, 78pp.

Carlsson, M.S., Glud, R.N. and Petersen, J.K. (2010). Degradation of mussel (*Mytilus edulis*) fecal pellets released from hanging long-lines upon sinking and after settling at the sediment. *Canadian Journal of Fisheries and Aquatic Sciences*, 67(9): 1376–1387.

CBD Secretariat (2004). Solutions for sustainable mariculture - avoiding the adverse effects of mariculture on biological diversity. Secretariat on the Convention on Biological Diversity. (CBD Technical Series no. 12). Quebec, Canada.

Chung, I.K., Beardall, J., Mehta, S., Sahoo, D. and Stojkovic, S. (2011). Using marine macroalgae for carbon sequestration: a critical appraisal. *Journal of Applied Phycology*, 23(5): 877–886.

Clavelle, T., Lester, S.E., Gentry, R. and Froehlich, H.E. (2019). Interactions and management for the future of marine aquaculture and capture fisheries. *Fish and Fisheries*, 20: 368–388.

Collins, C., Bresnan, E., Brown, L., Falconer, L., Guilder, J., Jones, L., Kennerley, A., Malham, S., Murray, A. and Stanley, M. (2020). Impacts of climate change on aquaculture. *MCCIP Science Review 2020*, 1: 482–520.

Cook, N., Williams, L. and D'Agostino, M. (2019). Prevalence of Norovirus in produce sold at retail in the United Kingdom. *Food Microbiology*, 79: 85–89.

Dauvin, J.C., Pezy, J.P., Baffreau, A., Bachelet, Q., Baux, N., Méar, Y. and Poizot, E. (2019). Effects of a salmon fish farm on benthic habitats in a high-energy hydrodynamic system: The case of the Rade de Cherbourg (English Channel). *Aquaculture*, 518: 734832.

Davies, S. and Blundell, F. (2019). Exe Estuary Cockle Stock Assessment 2010 – 2018. Devon and Severn Inshore Fisheries and Conservation Authority Research Report. Available at: https://www.devonandsevernifca.gov.uk/content/download/3775/29055/file/P Exe Estuary Cockle Survey 2010-2018 Report Final.pdf

Defra (2015). United Kingdom Multi-Annual National Plan for the Development of Sustainable Aquaculture. Defra, London, UK. 39pp. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/480928/sustainable-aquaculture-manp-uk-2015.pdf

DIPNET, 2007, Review of disease interactions and pathogen exchange between farmed and wild finfish and shellfish in Europe (Editors: Raynard, R., Wahli, T., Vatsos, I. and Mortensen, S.), Veterinærmedisinsk Oppdragssenter AS, ISBN 82-91743-74-6. 2007.

Donaghy, L., Hyun-Ki, H., Moonkoo, K.B., Heung-Sik, P. and Kwang-Sik, C. (2016). Assessment of the fitness of the mussel *Mytilus galloprovincialis* two years after the Hebei Spirit oil spill. *Marine Pollution Bulletin*, 113: 324–331.

European Parliament and Council (2004). Regulation (EC) No 854/2004 of the European Parliament and of the Council of 29 April 2004. Laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. *Official Journal of the European Union*, L226: 83–127.

FAO (2018). *The Global Status of Seaweed Production, Trade and Utilization.* Globefish Research Programme Volume 124. Food and Agriculture Organisation of the United Nations, Rome, Italy. 120pp. Available at: http://www.fao.org/3/CA1121EN/ca1121en.pdf

FAO (2019). FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: FAO Fisheries Division of the Food and Agriculture Organisation of the United Nations, Rome, Italy [online]. Available at: http://www.fao.org/fishery/statistics/software/fishstatj/en

FAO (2020). GLOBEFISH Highlights October 2019 ISSUE, with Jan. – Jun. 2019 Statistics – A quarterly update on world seafood markets. Globefish Highlights, no. 4–2019. Available at: http://www.fao.org/3/ca7459en/ca7459en.pdf

Fenkes, M., Shiels, H.A., Fitzpatrick, J.L. and Nudds, R.L. (2016) The potential impacts of migratory difficulty, including warmer waters and altered flow conditions, on the reproductive success of salmonid fishes. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 193: 11–21.

FitzGerald, F. (2008) *Shellfish Industry Development Strategy: Financial Impacts of Sporadic Pollution Events and Exceeded Discharge Agreements on Shellfish Operations*. Shellfish Association of Great Britain, London, UK. 67pp. Available at http://www.shellfish.org.uk/files/PDF/80109CSO Cost Report.pdf

Gentry, R.R., Alleway, H.K., Bishop, M.J., Gillies, C.L., Waters, T. and Jones, R. (2019). Exploring the potential for marine aquaculture to contribute to ecosystem services. *Reviews in Aquaculture*, 12: 499–512.

Gjedrem, T., Robinson, N. and Rye, M. (2012) The importance of selective breeding in aquaculture to meet future demands for animal protein: a review. *Aquaculture*, 350–353: 117–129.

Glibert, P.M. (2020) Harmful algae at the complex nexus of eutrophication and climate change. *Harmful Algae*, 91: 101583.

Grebe, G.S., Byron, C.J., St. Gelais, A., Kotowicz, D.M. and Olson, T.K. (2019). An ecosystem approach to kelp aquaculture in the Americas and Europe. *Aquaculture Reports,* 15: 100215.

Government Office for Science (2017). Foresight Future of the Sea: Trends in Aquaculture. Foresight – Future of the Sea Evidence Review. Government Office for Science, London, UK. 41pp. Available from: https://www.gov.uk/government/publications/future-of-the-sea-trends-in-aquaculture

Herbert, R.J.H., Humphreys, J., Davies, C.J., Roberts, C., Fletcher, S. and Crowe, T.P. (2016). Ecological impacts of non-native oysters (*Crassostrea gigas*) and management measures for protected areas in Europe. *Biodiversity and Conservation*, 25: 2835–2865.

Hilborn, R., Banobi, J., Hall, S.J. Pucylowski, T. and Walsworth, T.E. (2018). The environmental cost of animal source foods. *Frontiers in Ecology and the Environment,* 16: 329–335.

Humphreys, J., Herbert, R.J.H., Roberts, C. and Fletcher, S. (2014) A reappraisal of the history and economics of the Pacific oyster in Britain. *Aquaculture*, 428-429: 117–124.

Huntington, T. and Cappell, R. (2020). *English Aquaculture Strategy: Final Report.* Produced by Poseidon Aquatic Resources Management Ltd for the Seafish Industry Authority. 80pp + appendices. Available at: https://www.seafish.org/document/?id=9efe670c-847b-4a4f-b8ec-72f2e5396df6

Hutchison, Z.L., Hendrick, V.J., Burrows, M.T., Wilson, B. and Last, K.S. (2016) Buried alive: the behavioural response of the mussels, *Modiolus modiolus* and *Mytilus edulis* to sudden burial by sediment. *PloS one*, 11(3): e0151471.

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L.. (*eds*).]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1132pp. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf

ITOPF Ltd (2014). Technical Information Paper 11: Effects of oil pollution on fisheries and mariculture. International Tanker Owners Pollution Federation Limited. London, UK. 12pp. Available at: https://www.itopf.org/knowledge-resources/documents-guides/document/tip-11-effects-of-oil-pollution-on-fisheries-and-mariculture/

Jovic, M., Stankovic, A., Slavkovic-Beskoski, L., Tomic, I., Degetto, S. and Stankovic, S. (2011). Mussels as a bio-indicator of the environmental quality of the coastal water of the Boka Kotorska bay (Montenegro). *Journal of the Serbian Chemical Society*, 76(6): 933–946.

Kaiser, M.J. and Beadman, H.A. (2002). Scoping study of the carrying capacity for bivalve cultivation in the coastal waters of Great Britain. The Crown Estate. Interim Report: 39 pp.

Kaiser, M.J., Laing, I. and Burnell, G.M. (1998). Environmental impacts of bivalve mariculture. *Journal of Shellfish Research*, 17(1): 59 – 66.

Kavanagh, A., Hopkins, R. and Stainford, D. 2007. A review of research on the causes and quantities of farmed fish escapes from open net cage systems and a literature review of the impact of escapes on wild populations, using farmed salmon as case study. National Organic Standards Board Symposium.

Karel, E. (1999). Ecological effects of dumping of dredged sediments; options for management. *Journal of Coastal Conservation*, 5(1): 69–80.

Koch, M., Bowes, G., Ross, C. and Zhang, X.H. (2013). Marine macro-autotrophs and climate change. *Global Change Biology*, 19: 103–132.

Kroeker, K.J., Kordas, R.L., Crim, R., Hendriks, I.E., Ramajo, L., Singh, G.S. and Gattuso, J.P. (2013). Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biology*, 19(6), 1884–1896.

Laing, I., Walker, P. and Areal, F. (2006). Return of the native – is European oyster (*Ostrea edulis*) stock restoration in the UK feasible? *Aquatic Living Resources*, 19: 283–287.

Liu, H., Ye, T., Soon, T.K., Zhang, H., Cheng, D., Li, S. and Zheng, H. (2019) Effects of stocking density on the growth performance, bacterial load and antioxidant response systems of noble scallop *Chlamys nobilis. Fish and Shellfish Immunology*, 92: 40–44.

Lowther, J.A., Cross, L., Stapleton, T., Gustar, N.E., Walker, D.I., Sills, M. and Lees, D.N. (2019). Use of F-specific RNA bacteriophage to estimate infectious norovirus levels in oysters. *Food and Environmental Virology*, 11: 247–258.

Mainwaring, K., Tillin, H. and Tyler-Walters, H. (2014). *JNCC Report 506: Assessing the sensitivity of blue mussel beds to pressures associated with human activities.* Joint Nature

Conservation Committee, Peterborough, UK. 96pp. Available at: https://data.jncc.gov.uk/data/c1a80fb6-ac64-4a9c-aa13-2ab7a441937a/JNCC-Report-506-FINAL-WEB.pdf

Malcorps, W., Kok, B., van't Land, M., Fritz, M., van Doren, D., Servin, K., van der Heijden, P., Palmer, R., Auchterlonie, N.A., Rietkerk, M., Santos, M.J. and Davies, S.J. (2019). The sustainability conundrum of fishmeal substitution by plant ingredients in shrimp feeds. *Sustainability*, 11: 1212.

Mangi, S.C., Lee, J., Pinnegar, J.K., Law, R.J., Tyllianakis, E. and Birchenough, S.N.R. (2018). The economic impacts of ocean acidification on shellfish fisheries and aquaculture in the United Kingdom. *Environmental Science & Policy*, 86: 95–105.

McHugh, D.J. (2003). FAO Fisheries Technical Paper 441: A guide to the seaweed industry. Food and Agriculture Organisation of the United Nations, Rome, Italy [online]. Available at: http://www.fao.org/3/y4765e/y4765e00.htm

Michalek, K., Ventura, A. and Sanders, T. (2016). *Mytilus* hybridisation and impact on aquaculture: a minireview. *Marine Genomics*, 27: 3–7.

Natural England (2018). Condition Assessment for Plymouth Sound and Estuaries SAC. Available at: https://designatedsites.naturalengland.org.uk/MarineCondition/publicFeatures.aspx?SiteCode=UK0013111

Natural England (2020). Supplementary Advice on Conservation Objectives for the Dart Estuary MCZ. Available at: https://designatedsites.naturalengland.org.uk/Marine/SupAdvice.aspx?SiteCode=UKMCZ0057

Nehls, G., Diederich, S., Thieltges, D.W. and Strasser, M. (2006). Wadden Sea mussel beds invaded by oysters and slipper limpets: competition or climate control? *Helgoland Marine Research*, 60: 135–143.

Neori, A., Troell, M., Chopin, T., Yarish, C., Critchley, A. and Buschmann, A.H. (2007). The need for a balanced ecosystem approach to blue revolution aquaculture. *Environment: Science and Policy for Sustainable Development*, 49(3): 36–43.

OSPAR Commission (2009). *Assessment of Impacts of Mariculture*. 64 pp.

Parker, L.M., Ross, P.M., O'Connor, W.A., Borysko, L., Raftos, D.A. and Pörtner, H.O. (2011). Adult exposure influences offspring response to ocean acidification in oysters. *Global Change Biology*, 18(1): 82–92.

Pearson, T.H., Black, K.D. (2000). The environmental impacts of marine fish cage culture. 31pp. *In*: Black, K.D. (eds.) *Environmental Impacts of Aquaculture*. Sheffield Academic Press, Sheffield, UK. 219pp.

Peteiro, C. (2018). Alginate Production from Marine Macroalgae, with Emphasis on Kelp Farming. *In*: Rehm, B. and Moradali, M. (eds.). *Alginates and Their Biomedical Applications.* Springer Series in Biomaterials Science and Engineering, 11. Springer, Singapore. 279 pp.

Pinder, D. (2003). Seaport decline and cultural heritage sustainability issues in the UK coastal zone. *Journal of Cultural Heritage*, 4(1): 35–47.

Plew, D.R., Stevens, C.L., Spigel, R.H. and Hartstein, N.D. (2005) Hydrodynamic implications of large offshore mussel farms. *IEEE Journal of Oceanic Engineering*, 30(1): 95–108.

Pogoda, B., Brown, J., Hancock, B., Preston, J., Pouvreau, S., Kamermans, P., Sanderson, W. and Nordheim, H.V. (2019). The Native Oyster Restoration Alliance (NORA) and the Berlin Oyster Recommendation: bringing back a key ecosystem engineer by developing and supporting best practice in Europe. *Aquatic Living Resources*, 32(13).

Porter, G. (2003). Protecting wild Atlantic salmon from impacts of salmon aquaculture: a country-by-country progress report. World Wildlife Fund and Atlantic Salmon Federation, Washington, D.C.

Quilliam, R.S., Clements, K., Duce, C., Cottrill, S.B., Malham, S. and Jones, D.L. (2011). Spatial variation of waterborne *Escherichia coli* – implications for routine water quality monitoring. *Journal of Water and Health*, 9(4): 734–737.

Rayssac, N., Pernet, F., Lacasse, O. and Tremblay, R. (2010). Temperature effect on survival, growth, and triacylglycerol content during the early ontogeny of *Mytilus edulis* and *M. trossulus*. *Marine Biology Progress Series*, 417: 183–191.

Read, K.R.H., Cumming, K.B. (1967). Thermal tolerance of the bivalve mollusc *Modiolus modiolus* (L.), *Mytilus edulis* (L.) and *Brachiodontes demissus* (Dillwyn). *Comparative Biochemistry and Physiology*, 22: 149–155.

Reed, M., Courtney, P., Urquhart, J. and Ross, N. (2013). Beyond fish as commodities: understanding the socio-cultural role of inshore fisheries in England. *Marine Policy*, 37: 62–68.

Renault, T., Bouquet, A.L., Maurice, J.T., Lupo, C. and Blachier, P. (2014). Ostreid Herpesvirus 1 infection among Pacific oyster (*Crassostrea gigas*) spat: relevance of water temperature to virus replication and circulation prior to the onset of mortality. *Applied and Environmental Microbiology*, 80(17): 5419–5426.

Rice, S.D., Thomas, R.E., Carls, M.G., Heintz, R.A., Wertheimer, A.C., Murphy, M.L., Short, J.W. and Moles, A. (2001). Impacts to Pink Salmon following the Exxon Valdez oil spill: persistence, toxicity, sensitivity, and controversy. *Reviews in Fisheries Science*, 9(3):165-211.

Robins, P.E., Skov, M.W., Lewis, M.J., Giménez, L., Davies, A.G., Malham, S.K. and Jago, C.F. (2016). Impact of climate change on UK estuaries: a review of past trends and potential projections. *Estuarine, Coastal and Shelf Science*, 169: 119–135.

Ruiz, Y., Suarez, P., Alonso, A., Longo, E., Villaverde, A. and San Juan, F. (2011). Environmental quality of mussel farms in the Vigo estuary: pollution by PAHs, origin and effects on reproduction. *Environmental Pollution*, 159(1): 250–265.

Sanchez-Jerez, P., Karakassis, Y., Massa, F., Fezzardi, D., Aguilar-Manjarrez, J., Soto, D., … and Dempster, T. (2016). Aquaculture's struggle for space: The need for coastal spatial planning and the potential benefits of Allocated Zones for Aquaculture (AZAs) to avoid conflict and promote sustainability. *Aquaculture Environment Interactions*, 8: 41–54.

Seafood 2040 (2019). Seafood 2040 Annual Report: Year One, 11pp. Available at: https://www.seafish.org/document/?id=CA88F1AC-C3B7-4B47-B646-8F2F5FD0028A

Seed, R. and Suchanek, T.H. (1992). Population and community ecology of *Mytilus*. *In*: Gosling, E.M. (ed.) *The mussel Mytilus: ecology, physiology, genetics and culture.* Amsterdam: Elsevier, Amsteram. *Part of*: Developments in Aquaculture and Fisheries Science, 25. 589 pp.

Sheehan, E.V., Bridger, D., Cabre, L.M., Cartwright, A., Cox, D., Rees, D., Holmes, L.A. and Pittman, S.J. (2019). Bivalves boost biodiversity. *Journal of the Institute of Food Science and Technology*. 33(2): 18–21.

Shumway, S.E., Davis, C.V., Downey, R., Karney, R., Kraeuter, J.N., Rheault, R.B. and Wikfors, G.H. (2003). Shellfish aquaculture: in praise of sustainable economies and environments. *World Aquaculture*, 34(4): 15–18.

Solé, M., Porte, C., Biosca, X., Mitchelmore, C.L., Chipman, J.K., Livingstone, D.R. and Albaigés, J.(1996). Effects of the “Aegean Sea” oil spill on biotransformation enzymes, oxidative stress and DNA-adducts in digestive gland of the mussel (*Mytilus edulis*, L.). *Comparative Biochemistry and Physiology Part C: Pharmacology, Toxicology and Endocrinology*, 113(2): 257–265.

Stagg, R.M., Rusin, J., McPhail, M.E., McIntosh, A.D., Moffat, C.F. and Craft, J.A. (2009). Effects of polycyclic aromatic hydrocarbons on expression of cyp1a in salmon (*Salmo salar*) following experimental exposure and after the Braer oil spill. *Environmental Toxicology and Chemistry*, 19(11): 2797–2805.

Stewart, J.E. and Wentworth, J. (2019). *POSTnote 604: Climate Change and Fisheries*. Parliamentary Office of Science and Technology, London, UK. Available at: https://post.parliament.uk/research-briefings/post-pn-0604/

Sylvester, E.V.A., Wringe, B.F., Duffy, S.J., Hamilton, L.C., Fleming, I.A., Castellani, M., Bentzen, P. and Bradbury, I.R. (2018). Estimating the relative fitness of escaped farmed salmon offspring in the wild and modelling the consequences of invasion for wild populations. *Evolutionary Applications*, 12 (4): 705–717.

Tacon, A.G.J. (2020). Trends in global aquaculture and aquafeed production: 2000–2017. *Reviews in Fisheries Science and Aquaculture*, 28(1): 43–56.

Talmage, S.C., Gobler, C.J. (2010). Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish. *Proceedings of the National Academy of Sciences of the United States of America*, 107: 17246–17251.

Townhill, B.L., Tinker, J., Jones, M., Pitois, S., Creach, V., Simpson, S.D., Dye, S., Bear, E. and Pinnegar, J.K. (2018). Harmful algal blooms and climate change: exploring future distribution changes. *ICES Journal of Marine Science*, 75(6):1882–1893.

Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A.H., Kautsky, N. and Yarish, C. (2003). Integrated mariculture: asking the right questions. *Aquaculture*, 226(1–4): 69–90.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A.H. and Fang, J.-G. (2009). Ecological engineering in aquaculture – potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture*, 297: 1–9.

Vendrami, D.L.J., De Noia, M., Telesca, L., Brodte, E.M. and Hoffman, J.I. (2020). Genome-wide insights into introgression and its consequences for genome-wide heterozygosity in the *Mytilus* species complex across Europe. *Evolutionary Applications*, 13(8): 2130–2142.

Visch, W., Kononets, M., Hall, P.O.J., Nylund, G.M. and Pavia, H. (2020). Environmental impact of kelp (*Saccharina latissimi*) aquaculture. *Marine Pollution Bulletin,* 155: 110962.

Walls, A., Kennedy, R., Edwards, M. and Johnson, M, (2017). Impact of kelp cultivation on the ecological status of benthic habitats and Zostera marina seagrass biomass. *Marine Pollution Bulletin,* 123: 19–27.

Wang, L., Fan, Y., Yan, C., Gao, C., Xu, Z. and Liu, X. (2017). Assessing benthic ecological impacts of bottom aquaculture using macrofaunal assemblages. *Marine Pollution Bulletin*, 114(1): 258–268.

Yang, G., Song, L., Lu, X., Wang, N. and Li, Y. (2018). Effect of the exposure to suspended solids on the enzymatic activity in the bivalve *Sinonovacula constricta*. *Aquaculture and Fisheries*, 2(1): 10–17.