Workshop on the Celtic Seas Ecoregion Aquaculture Overview

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Contents

i Executive summary iv
ii Expert group information v
1 Introduction 6
1.1 Habitats 6
1.2 Conservation Areas 9
1.3 Physical Oceanography 10
1.4 Temperature 11
2 Description and location of marine aquaculture activities and practices 14
2.1 Introduction 14
2.2 Ireland 14
Cultivation methods and species grown 14
2.2.1 Ireland – oyster trestle (intertidal) 15
2.2.2 Ireland – mussel (suspension-rope) 16
2.2.3 Ireland – mussel (bottom) 17
2.2.4 Ireland – finfish (cages - marine) 18
2.2.5 Ireland – seaweed culture 20
2.2.6 Ireland – other species 20
2.3 The UK 22
2.4 Northern Ireland 22
2.4.1 Northern Ireland – oysters trestle (intertidal) 22
2.4.2 Northern Ireland – mussels (suspended) 24
2.4.3 Northern Ireland – mussels (bottom cultivated) 24
2.4.4 Northern Ireland – finfish 25
2.4.5 Northern Ireland – seaweed 26
2.4.6 Northern Ireland – other species 26
2.5 Scotland 26
2.5.1 Scotland – oyster trestle (intertidal) 28
2.5.2 Scotland – mussel (suspension- rope) 28
2.5.3 Scotland – mussel (bottom) 29
2.5.4 Scotland – finfish (cages- marine) 29
2.5.5 Scotland – seaweed 29
2.5.6 Scotland – other shellfish 30
2.6 Wales 30
2.6.1 Wales – oyster trestle (intertidal) 30
2.6.2 Wales – mussel (suspension- rope) 31
2.6.3 Wales – mussel (bottom) 31
2.6.4 Wales – finfish (cages- marine) 31
2.6.5 Wales – seaweed culture 31
2.6.6 Wales – other shellfish 32
2.7 England 34
2.7.1 England – oyster trestle (intertidal) 34
2.7.1.1 England – Pacific oyster (bottom) 34
2.7.2 England – mussel (suspension- rope) 34
2.7.2.1 England – mussel (bottom) 35
2.7.3 England – finfish (cages- marine) 35
2.7.4 England – seaweed 35
2.7.5 England – other shellfish 35
2.8 Channel Islands 36
2.8.1 Jersey – oyster trestle (intertidal) 36
2.8.2 Jersey – mussel (“Bouchot”) 37

2.8.3 Guernsey ... 37
2.9 Conclusions ... 37
3 Production over time – Ireland, United Kingdom and Crown Dependencies ... 38
3.1 Data sources and gaps ... 38
3.2 Total production over time ... 40
3.3 Finfish ... 41
3.3.1 On-grown production (finfish) ... 41
3.3.2 Hatchery production for ongrowing (finfish) ... 42
3.3.3 Hatchery production for environmental stocking (finfish) ... 43
3.3.4 Wild production input to aquaculture (finfish) ... 44
3.4 Molluscs ... 44
3.4.1 On-grown production (molluscs) ... 44
3.4.2 Hatchery production for ongrowing (molluscs) ... 47
3.4.3 Hatchery production for environmental stocking (molluscs) ... 47
3.4.4 Wild production input to aquaculture (molluscs) ... 47
3.5 Crustaceans ... 48
3.5.1 On-grown production (crustaceans) ... 48
3.5.2 Hatchery production for ongrowing and environmental stocking (crustaceans) ... 48
3.6 Other marine invertebrates ... 48
3.7 Seawater plants ... 49
4 Policy and Legal Foundation ... 51
4.1 Licensing ... 51
4.1.1 Ireland ... 51
4.1.2 Northern Ireland ... 53
4.1.3 Transboundary areas ... 54
4.1.4 Scotland ... 55
4.1.5 England ... 55
4.1.6 Wales ... 56
5 Management Frameworks ... 58
5.1 Aquaculture Health Regulations ... 58
5.1.1 Ireland ... 58
5.1.2 Northern Ireland ... 58
5.1.3 Scotland ... 59
5.1.4 England and Wales ... 59
5.2 Monitoring and Management ... 59
5.2.1 Ireland ... 59
5.2.2 Northern Ireland ... 61
5.2.3 Scotland ... 62
6 Ecosystem/Environment Interactions ... 63
6.1 Introduction ... 63
6.2 Salmonid farming ... 63
6.2.1 Nutrient wastes ... 63
6.2.2 Disease interactions ... 65
6.2.3 Escapes ... 66
6.2.4 Chemical treatments ... 68
6.2.5 Marine mammals ... 69
6.3 Bivalves ... 70
7 Social and Economic Context ... 71
7.1 What, Where and How? ... 71
Data sources ... 71
7.2 Scale/Capacity ... 71
7.3 Issues and Trends ... 73
8 Interaction of environmental, economic and social drivers ... 75

8.1 Environmental, economic and social drivers of aquaculture 75
8.2 Environmental, economic and social interactions 76
8.3 Aquaculture planning to manage environmental, economic and social interactions – case studies 78
8.4 Seaweeds 80
8.5 Limitations of aquaculture planning approaches 86
9 Future projections and emerging threats and opportunities 87
9.1 Legislative drivers – Brexit, marine plans and recent consultations 87
9.2 Application processes and future development 88
9.2.1 Development trends 88
9.3 Climate change and ocean acidification 90
9.4 Disease 91
9.5 SWOT analysis 92
10 References 95
Annex 1: List of participants 106
Annex 2: Resolutions 107
Annex 3: Review Group Consensus Report 108
Annex 4: Responses from WKCSAO to RGCSAO Report 119
Annex 5: Advice Drafting Group Meeting Minutes 126

i Executive summary

The Workshop on Celtic Seas Aquaculture Overview (WKCSAO) was established to assemble and synthesize aquaculture related data and information from the Celtic Seas ecoregion to inform the Celtic Seas ecoregion aquaculture overview.

The Celtic Seas ecoregion comprises much of the UK and all Ireland. Aquaculture is practised in all coastal waters. Both intertidal and subtidal waters are used for aquaculture. In the UK, aquaculture regulation and policy are devolved to the four countries: England, Scotland, Wales, and Northern Ireland. In addition to Ireland, there are five separate countries with potentially diverse aquaculture policy drivers and regulatory frameworks within the Celtic Seas ecoregion.

Marine aquaculture production within the ecoregion is dominated by finfish, largely produced in Scotland. However, molluscs dominate in the other countries - Ireland, Northern Ireland, England, Wales, and the Channel Islands. Seawater aquaculture is currently focused on 4 main species that have all been farmed for > 40 years: Atlantic salmon, mussels (*Mytilus* spp.), Pacific cupped oyster and rainbow trout.

In Ireland and the UK, small production units (< 5 employees) predominate. However, in both countries, more capital-intensive operations (i.e. finfish sector and larger shellfish farms) tend to operate multiple production units and will employ more people. Of note, the employment status (based upon FTEs) is more stable for the finfish sector than shellfish sector, which comprises larger proportion of part-time employment. While the overall employment is considered modest, the importance of these (even part-time) roles in more isolated rural areas is acknowledged.

Environmental monitoring of aquaculture is primarily focused on finfish culture practices in all countries where impacts on habitats and wild salmonids are considered. Monitoring of shellfish culture practices are primarily focused upon food safety considerations, e.g. biotoxin and faecal coliform analysis. All species are subject to extensive animal health regulations that are wide ranging and derives primarily from EU legislation.

In common with many production areas the primary environmental impacts relate to interference on habitats and species. More specifically, for finfish culture, sea lice, genetic introgression from escaped farmed salmon and disease transmissions from salmon farms are considered as threats to wild salmon. Impacts on overwintering shore birds has been described in relation to intertidal culture operations (oysters and clams). Other environmental interactions considered include emissions of dissolved nutrients, particulate organic matter, pollutants and therapeutants.

A number of case studies are presented where likely interactions among social, economic and ecological drivers and presented solutions to avoid conflict are presented including open communication among all stakeholders, wider socio-economic consideration and filling knowledge gaps in environmental interactions.

A number of issues are identified which may affect aquaculture development and are considered common across the ecoregion. The geopolitical constraints to trade imposed by Brexit is of note. Delays and potential legal challenges associated with licencing decisions. Of particular concern are the potential effects of climate change and subsequent follow-on effects relating to disease, for example, in culture stock.

ii Expert group information

Expert group name	Workshop on the Celtic Seas Ecoregion Aquaculture Overview (WKCSAO)
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chairs	Francis O'Beirn, Ireland
	Henn Ojaveer, Denmark
Meeting venue and dates	26–29 April 2022, online meeting (16 participants)

1 Introduction

ICES work on aquaculture is part of a wider portfolio of work that seeks to advance and share scientific understanding of marine ecosystems and the services they provide, and to use this knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals. ICES has established aquaculture overviews, which in this instance for the Celtic Seas ecoregion will attempt to:

i. summarize regional and temporal information on aquaculture activities, practices, and production of the cultured taxa;
ii. describe the relevant policy and legal foundation and management systems;
iii. consider the environmental and socio-economic interactions of aquaculture activities and practices and how these interactions influence the policy and planning of aquaculture in various jurisdictions;
iv. consider future projections and emerging threats and opportunities and,
v. identify gaps in information allowing precise management actions to be undertaken.

Aquaculture practices (and species cultured) within the Celtic Seas ecoregion are varied and consist of a range of both intensive finfish and extensive shellfish production practices. The locations of aquaculture activities are also highly varied and range from intertidal and subtidal habitats. As a consequence, aquaculture practices, depending on the species and systems in question, are carried out in estuarine and more open coastal shorelines to deeper water sheltered embayments. Important considerations in relation to locating aquaculture activities is the ability to access the areas in question either by boat and or over the intertidal areas using vehicles. When considering access to culture sites, it would be important that appropriate shore-based (i.e. terrestrial) facilities are appropriately located.

This report, in addition to providing a broad summary of practices and management systems, also seeks to set the social and economic context for aquaculture in the ecoregion describing the key drivers of aquaculture development and whether these drivers negatively or positively affect the nature as well as the extent of aquaculture development in the region over time, for example local food supplies and income/job creation vs. international market demands and competition.

The inclusion of the interaction of environmental, economic, and social drivers is an important component of this advisory product. It attempts to provide the most recent understanding on the potential environmental, economic, and social interactions to aid aquaculture planning. It also indicates the growing capability of ICES expert network to address socio-economic issues.

In addition, perspectives on threats and opportunities are provided in this report. For example, effects of climate change, biological or ecological threats associated with aquaculture activities, and development trends (incl. emerging candidate species and production methods) are considered.

1.1 Habitats

The Celtic Seas ecoregion covers the northwestern European continental shelf and seas, from western Brittany in the south to Shetland in the north. It is bounded by five other ICES ecoregions (Figure 1.1). The Faroes and Norwegian Sea to the north and northeast and Greater North Sea to the east. In addition, the Bay of Biscay and the Iberian coast bound the southern border. To the west is the Oceanic Northeast Atlantic.

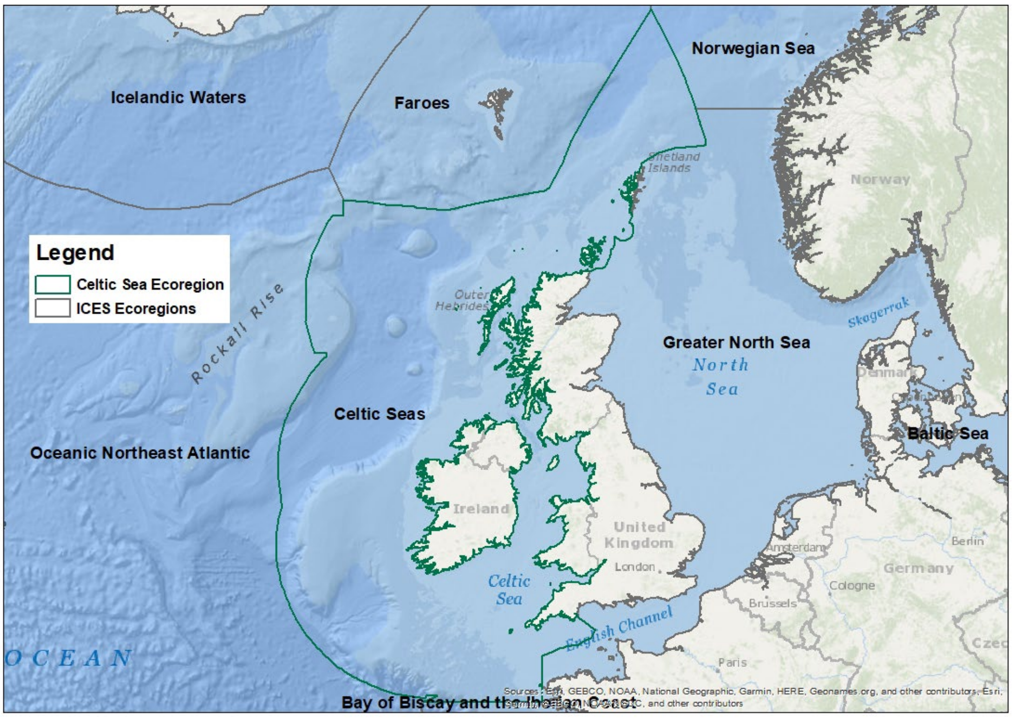

Figure 1.1 The Celtic Seas and other ICES Ecoregions.

The oceanography and climate of the region is strongly influenced by conditions in the adjacent Atlantic Ocean, particularly along the continental shelf edge where water exchange occurs between the ocean and shallow shelf seas (< 200 m depth). Ocean currents support strong linkages between the Celtic Seas ecoregion and its neighbouring ecoregions. The Rockall Trough is an important pathway for the transport of warmer and more saline water from the Northeast Atlantic to more northerly ecoregions. Water transport on the shelf is primarily from south to north, and prevailing southwesterly winds from the west and south.

The area and habitats (Figure 1.2) constituting this ecoregion are summarised as follows:

- The west of Scotland region consists of shallow shelf regions of the Shetland Shelf, Malin Shelf, Hebridean islands, and the coastal area between the Scottish mainland and the islands (including the Minch), and the adjacent deep-sea region of the Faroe–Shetland Channel.
- The Celtic Seas continental shelf (< 200 m), with southern and western boundaries delimited by sharp changes in bathymetry at the shelf edge.
- The continental shelf ecoregion to the west of Ireland, which is limited westward by the Rockall Trough, with the Goban Spur and Porcupine Bank forming long extensions of the coastal continental shelf.
- The relatively shallow, semi-enclosed Irish Sea. A higher density of large cities in this region leads to a potential concentration of human pressures.
- The broader Celtic Seas ecoregion is characterized by a diversity of habitats, such as an extensive slope, canyons, ridges, and seamounts that support vulnerable marine ecosystems (VMEs) concentrated within northwest Scotland, west of Ireland, and the Celtic Seas ecoregion (Figure 1.2).
- The seabed of the Celtic Seas ecoregion is primarily comprised of sediments with extensive areas of mixed sediments: coarse and sandy to muddy areas on the Malin shelf, coarse and mixed sediments with some muddy patches in the Irish Sea, and coarse, rocky,

and sandy to muddy sands in the Celtic Seas. Areas of rock and hard substratum are also present in the northern and inshore parts of the ecoregion.

- Nearshore and coastal habitats in the Celtic Seas ecoregion are diverse and range from exposed rocky shorelines to highly sheltered embayments and sea lochs. In addition, large expanses of intertidal sand and mud flats can be found in the ecoregion, particularly in estuarine areas.

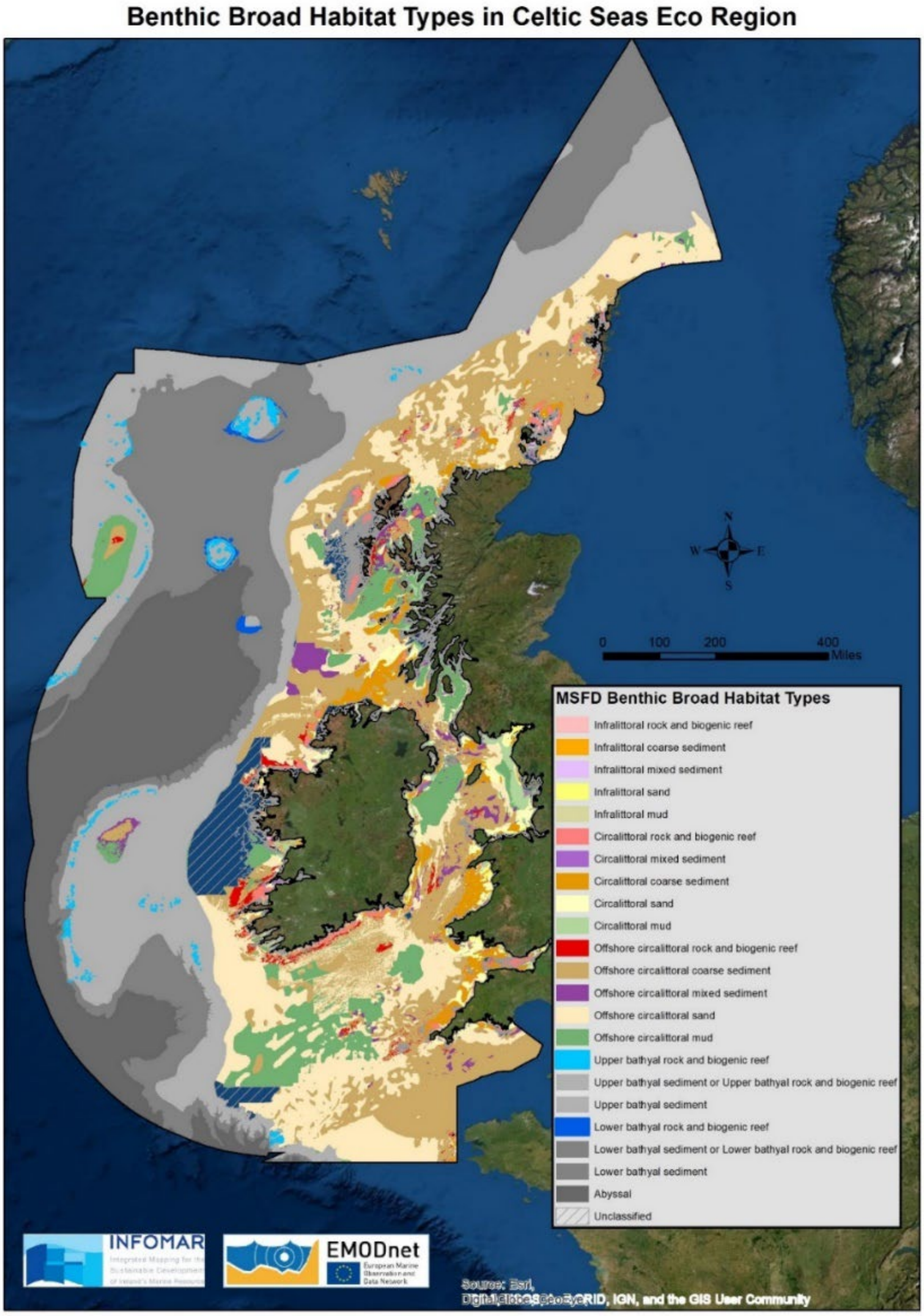

Figure 1.2 Broadscale substrate map of the Celtic Seas ecoregion as compiled by MESH Atlantic (www.emodnet.eu).

1.2 Conservation Areas

Of particular importance when planning aquaculture activities is giving due consideration to likely sensitivities in the areas proposed. To this end, identifying the location of conservation areas or features is critically important when assessing likely interactions. Under international (EU and OSPAR) and national legislation there are many mechanisms that designate conservation areas and are titled, among others, Marine Protected Areas, Special Areas of Conservation, Natural Heritage Areas, Site of Special Scientific Interest (SSSI). Figure 1.3 identifies many of those conservation areas in the Celtic Seas ecoregion with marine habitat and species components. While many of the offshore sites may have interactions with other marine sectors (offshore renewable energy developments, fisheries in addition to oil and gas exploration/activities) it is those conservation areas in nearshore or intertidal areas that would be of particular relevance to aquaculture managers in the Celtic Seas ecoregion. It should be noted the figure below relates primarily to areas designated for marine habitats and species (e.g. marine mammals) but does not include those areas designated for birds which should be considered equally as important during licencing deliberations and assessing likely interactions.

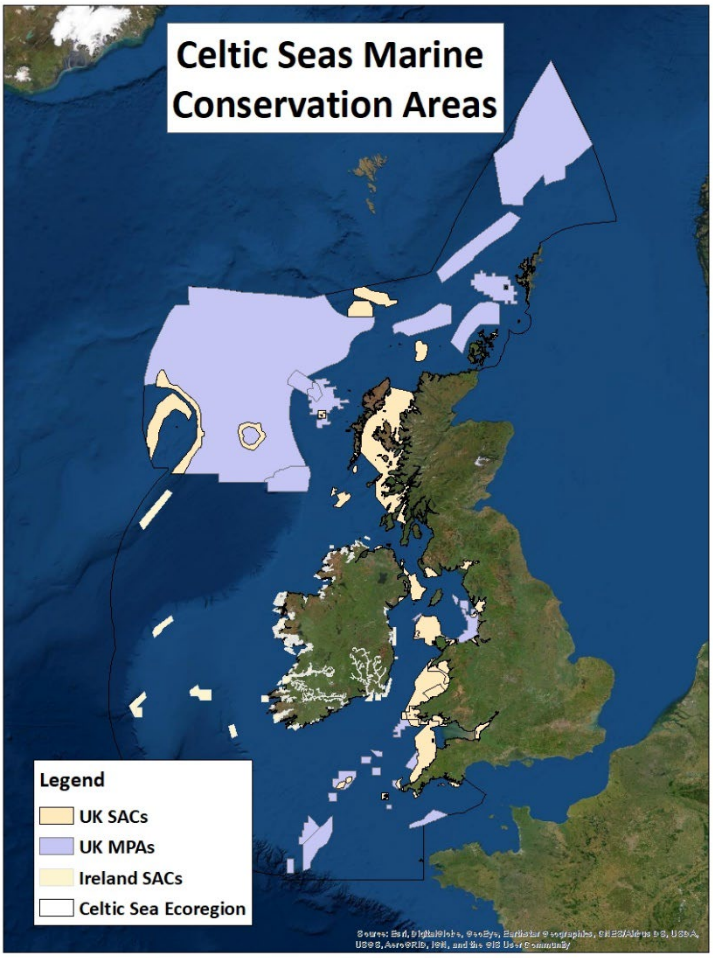

Figure 1.3 Conservations areas within the Celtic Seas ecoregion.

1.3 Physical Oceanography

The waters in the Celtic Seas ecoregion are generally stratified in summer and autumn and then mixed in winter and spring (ICES 2013). The main features of the circulation in the southern portion of the ecoregion are presented in Figure 1.4 and comprise frontal regions at the entrances to the Irish Sea and English Channel (Celtic Seas and Ushant Fronts), and the Western Irish Shelf Front. The other main feature is the Irish Slope current, which is part of the wider European Shelf Edge Current. This is generally in a poleward direction in winter and spring but can reverse in summer. There are also gyres found in the area of the Goban spur and Porcupine Bank. Further north in Scotland Celtic Seas interaction with the greater North Sea are significant (Scotland's National Marine Plan 2015). Scotland's position on the continental shelf means that the seas around Scotland are heavily influenced by oceanic circulation. The steep bathymetry of the continental slope acts as a barrier between oceanic regions and the shelf sea systems, reducing the amount of water that can travel from the deeper waters of the North Atlantic into the shallower waters on the continental shelf. Processes that cause mixing of oceanic waters and shelf seawaters are complex but have a significant effect on conditions in Scottish waters. Most waters from the North Atlantic that enter the North Sea do so between Orkney and Shetland, around the north-east of Shetland and through the deep Norwegian Trench (Figure 1.5).

Such physical forcing and broader environmental conditions result in highly productive waters which are considered highly suited for the production of shellfish and finfish.

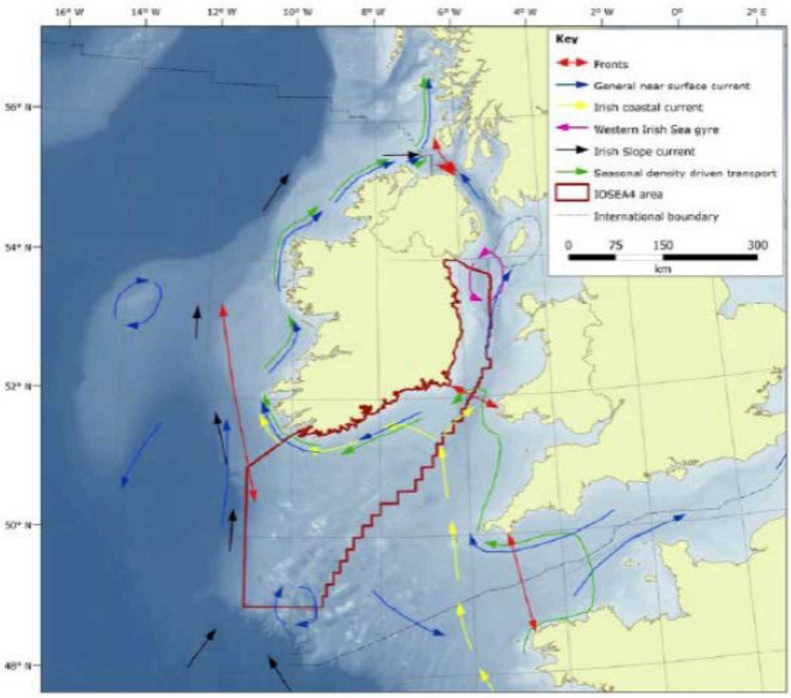

Figure 1.4 Ocean circulation patterns in nearshore areas southern portion of Celtic Seas ecoregion (ICES 2013).

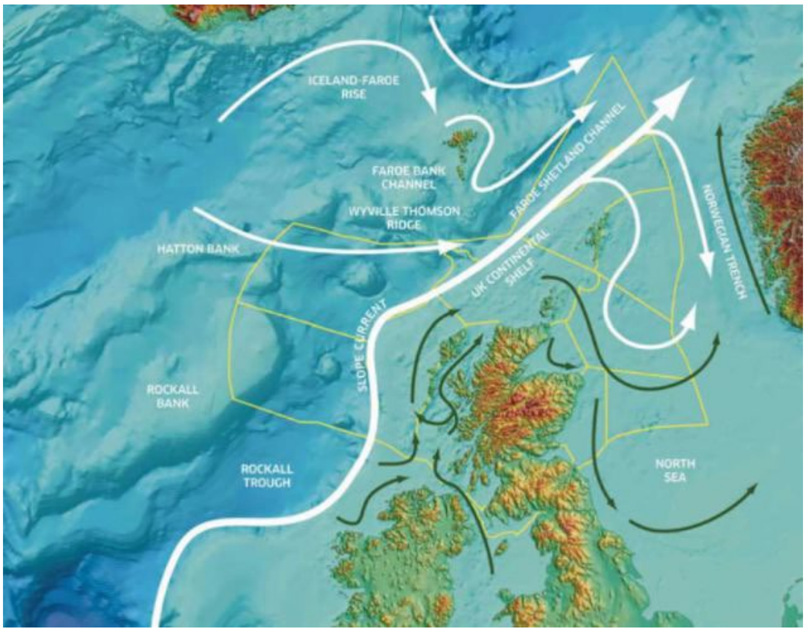

Figure 1.5 Ocean Circulation patterns in interface between Celtic Seas and Greater North Sea around Scotland (Baxter et al. 2011).

1.4 Temperature

Seawater temperature is an important variable for marine aquaculture. The optimum temperature is critical in defining the suitability of an area for aquaculture operation and ultimately the success related to aquaculture ventures. Certain species have wider tolerance range than others. Increasing temperatures may result in greater stress and subject the culture organisms to higher risk of infection from parasites or disease-causing organisms. In addition, increasing temperature may facilitate the northerly migration of non-native species. Sea surface temperature (SST) is an important measurement in predicting the success of aquaculture ventures. Mean annual SST in the Celtic Seas ecoregion has shown an overall upward trend of about +0.5°C since 1975, with a steeper rise from 1980–2005 and a broadly flat trend since (Figure 1.6).

Increasing temperature in the marine environment has been postulated to affect aquaculture in a number of ways, some considered positive others negative. It is expected that growth rates of species will increase. Problems may present themselves as they relate to greater risk and prevalence of disease-causing organisms. In addition, increasing incidences of harmful algal blooms as well as jellyfish swarms are expected, which will impact on both finfish and shellfish.

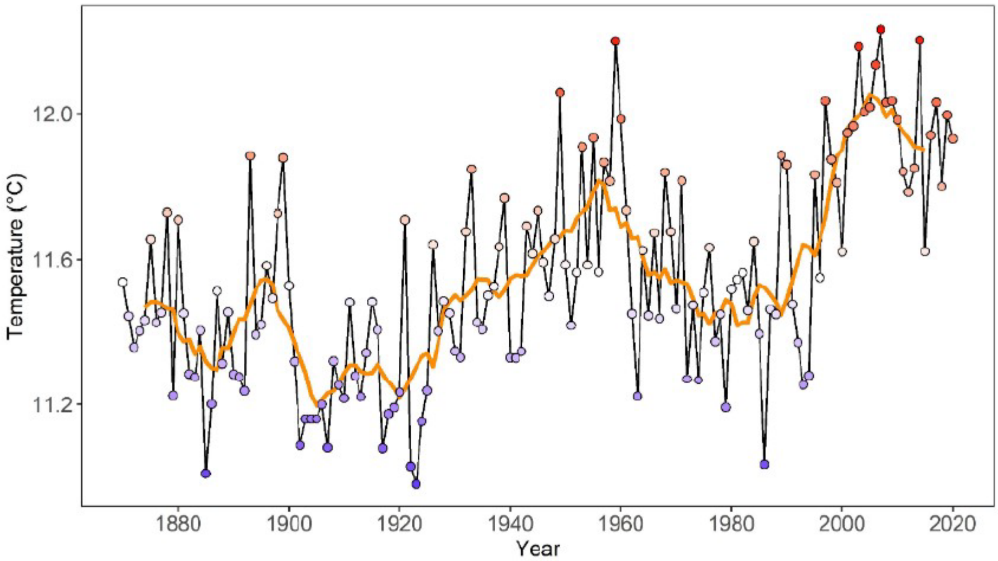

Figure 1.6 Mean annual sea surface temperature of the Celtic Seas (1970–2020) with a ten-year moving average (orange line). Within the Celtic Seas, there is little evidence of any major changes in salinity from long-term observation at the Western Channel Observatory (Source ICES 2021).

Long-term SST data are available throughout the Celtic Seas and is summarised in Table 1.1 below.

Table 1.1 Broad temperature summaries in Celtic Seas ecoregion derived from a variety of sources and linked to Figure 1.7 below.

Region	Mean SST (°C)	Min SST (°C)	Max SST (°C)
Scotland[1,2]			
Northern North Sea	09.49	6	14
Irish Sea	10.08	4	18
Minches and Western Scotland	10.22	6	15
Scottish Continental Shelf	10.17	6	14
Atlantic Northwest Approaches	-	9	14
Ireland[3]			
M1	12.5	8.9	18.1
M2	11.5	6.2	19.3
M3	13.0	9.5	20.4

[1] https://www.gov.scot/publications/scotlands-marine-atlas-information-national-marine-plan/pages/9/

[2] https://marine.gov.scot/information/annual-mean-surface-temperature

[3] http://data.marine.ie/geonetwork/srv/eng/catalog.search#/metadata/ie.marine.data:dataset.2783

M4	12.0	7.1	19.6
M5	12.5	8.0	20.1
M6	12.8	8.5	18.3
AMETS	12.3	9.3	15.8
Northern Ireland[4]			
AFBI Western Irish Sea Mooring	11.8	6.1	19.7

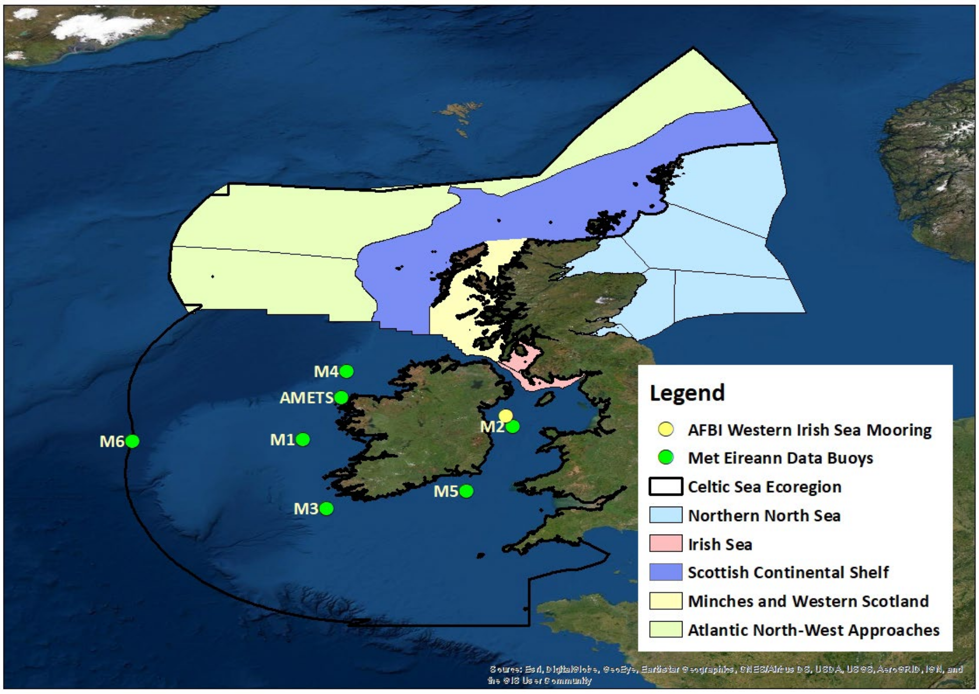

Figure 1.7 Summary locations for sea surface temperature statistics identified in Table 1.1 above.

[4] Reference from AFBI

2 Description and location of marine aquaculture activities and practices

2.1 Introduction

In this chapter we have defined marine aquaculture as the cultivation of finfish, shellfish and seaweed that will usually require a producer/ grower on-growing the species of choice on a licensed marine aquaculture/mariculture site. Marine related aquaculture activities that include fisheries for other shellfish and for England, cleaner fish facilities that extract marine water have been described.

Native oyster (*Ostrea edulis*) fisheries exist in all the Celtic Sea areas and are discussed in the subsequent sections. Until recently, this species has been classed as a wild fishery however there are different levels of management of these fisheries, yet many of which employ techniques commonly used in aquaculture practices. Fishery management in the respect that permits are required to fish native oysters in most of the Celtic Seas ecoregion and restrictions are in place to maintain the stocks. Historically native oyster fisheries thrived in many parts of the ecoregion. However, overfishing, disease, pollution and habitat loss were responsible for a large decrease in stocks or the complete collapse of many of these fisheries. Recent restoration projects have focused on native oysters and there are many examples of restoration projects in the Celtic Seas ecoregion. These are not all included in this chapter but it is important to note this for future aquaculture overviews.

2.2 Ireland[5]

Cultivation methods and species grown

Irish Aquaculture is primarily marine-based, occurring from the sheltered intertidal zone to exposed deep inshore waters. It is located within the various bays of the west coast, from Donegal to Cork and within the Estuarine bays of the southeast and northeast. The species farmed are mainly salmonid finfish and bivalve shellfish. There are a small number of inland finfish production units and several land-based shellfish hatcheries.

The Irish coastal zone varies in levels of shelter, depth, bottom type and hydrodynamics to the extent that a combination of suspended, off-bottom and on-bottom culture techniques are applied, depending on the species farmed. The deep and sheltered bays of the Southwest and Northwest provide the ideal locations for suspended mussel culture, with more exposed sites at their mouths providing sites for penned salmon culture. Shallow estuarine bays are widespread along the coast and depending on the particular bay dynamics, provide suitable conditions for either trestle oyster or seabed cultured oyster, mussel or scallop culture. The main species/culture groups therefore are penned Atlantic salmon (*Salmo salar*), farmed Pacific oyster (*Magallana gigas*), suspended rope and seabed cultured blue mussel (*Mytilus edulis*). Other coastal cultures are seabed cultured European flat oyster (*Ostrea edulis*) and king scallop (*Pecten maximus*), land-based shellfish and suspended rope seaweeds.

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[5] Summary statistic on extent of aquaculture licencing was sourced from the AQUAMIS online public aquaculture viewer (to be launched in May 2022). (https://dafm-maps.marine.ie/aquaculture-viewer/)

Inland, Atlantic salmon hatcheries supply the marine units and land-based rainbow trout (*Onychorhyncus mykiss*) units supply consumer niche markets

2.2.1 Ireland – oyster trestle (intertidal)

Two species of oyster are cultivated in Ireland, the native flat oyster, *Ostrea edulis* and the Pacific oyster, *Magallana gigas*. The decline in native oyster stocks due to overfishing and disease (e.g. *Bonamia*) has resulted in the introduction in the mid-1970s of the Pacific oyster. This species now dominates oyster culture operations in Ireland.

The culture of oysters is located predominantly in sheltered areas along the south, west and northwest coasts of Ireland (Figure 2.1). The majority of oyster culture in Ireland is off-bottom using bags and trestles in the intertidal zone (intertidal oyster cultivation). The bags or plastic 'pouches' are mesh bags that allow water to flow through the bags bringing food to the oysters. The oyster trestles vary in height but typically do not exceed 0.5 m height and their height above the sediment is often less as they sink into the sediment over time. It should be noted, that not all culture practice works with single bags, some systems culture oysters in stacked cages or in cages suspended from trestles or longlines in intertidal areas. However, such systems are rare and their environmental impact can be quite different from that of the standard oyster trestle system.

Oyster trestles are usually arranged in paired rows with a separation of around 4 m between rows and with wider (10–20 m) access lanes. The rows are usually orientated more or less perpendicularly to the tideline.

Oyster spat, supplied by hatcheries, is placed in the mesh bags. The mesh bags are secured on top of the trestles, where they are on-grown until they are ready for harvesting. The function of the trestles is to keep the animals off the seabed, preventing grit getting inside the oysters, providing increased water flow and allowing suitable shell growth. The mesh bags facilitate handling and prevent predation. As the oysters grow they are graded and transferred to mesh bags of wider mesh at lower densities. Husbandry activities involve turning the mesh bags on every spring tide to rid the bags of any settled silt, stop the growth of oyster shell into the mesh and destroy fouling organisms. Typically, visits to the sites are dictated by the seasons and the degree of maintenance required. Grading oysters and cleaning bags (due to fouling) during summer can require almost daily visits to sites. At other times the sites are visited less frequently. Intertidal oyster cultivation is labour intensive at low tide when the trestles are exposed, with constant maintenance of trestles to stop them from sinking and turning the bags to reduce biofouling.

Access to sites is, primarily, over the intertidal zone, usually using tractors (with trailers), although some sites are accessed via boats exclusively. Mostly, fixed routes are used to the culture plots from terrestrial bases. The sedimentary habitats where intertidal oyster culture is located must be such that the trestles do not sink quickly and that access is easy for permitted vehicles. Therefore, they are located in sheltered intertidal areas with firm sand or mixed sediments.

Oyster spat are typically sourced from hatcheries in France and/or the UK. In addition, some sites are used as intermediate production areas and will take in ½-grown oysters from other areas within Ireland or from outside the jurisdiction for "finishing" (growing to harvest size). The full oyster production cycle is variable ranging from 18 to 24 months, depending on a number of factors including size and source of spat, environmental conditions and good site maintenance and husbandry.

In Ireland, the number of intertidal licenced sites for off-bottom oyster culture is 511 (Table 2.1). In addition, bottom oyster culture occurs where partially grown oysters are deposited in licenced areas on the seabed and harvested via dredging. Both the Native oyster (*Ostrea edulis*) and the Pacific oyster (*Magallana gigas*) are cultured in this manner, with 30 and 12 sites licenced sites respectively (Table 2.1). In addition, the mean size of a licenced oyster plot is 3.78 ha and range from 0.07 ha to 69.4 ha.

This method of off-bottom Pacific oyster trestle cultivation has been noted throughout the Celtic Seas ecoregion and hereafter in this text will be referred to as the Irish off-bottom Pacific oyster culture method.

2.2.2 Ireland – mussel (suspension-rope)

Rope culture of mussels requires access to sheltered areas with deep water. Given the specialist vessels used for this culture method access from pier infrastructure as well as deep water >15 m are also required. It is for this reason that, in Ireland, rope mussel culture is concentrated primarily in large embayments in the southwest and in a small number of areas on the west and northwest coast (Figure 2.1).

Mussel seed for this culture method relies heavily on settlement from the water column, normally in the culture bays. In addition, the industry has also collected and used mussel seed sourced from intertidal reef habitats. This source of seed is not common and if occurring, is confined to isolated areas away from conservation zones.

The culture method involves placing, settlement media (rope, strap, mesh) in the water column, known as a 'dropper' on which natural juvenile mussels settle which, depending on a number of seasonal and local factors this takes place in April, May or June of each year. The collected mussel seed is then on-grown for typically 18–24 months before being harvested as per market requirements and in line with shellfish and water quality parameters.

As these mussels grow the 'droppers' are often moved from seed collection areas to grow-out areas, or remain *in situ*. Some farms grade the mussels during the 18–24 months whereby the mussels are re-packed at a specific density using bio-degradable cotton mesh around the rope, the mesh rots away after the mussels have re-attached using their byssal threads. All of the longlines in use are double headrope longlines, constructed from polypropylene mostly of 110m in length, with typically 30 x 210-250 L floatation units (mostly grey in colour) and anchored at each end with 2.5 tonne concrete weights. In general, the longline density is no greater than 3 lines per hectare. Licenced Rope mussel sites in Ireland have an average size of 5.78 ha, and range from 0.4 to 66 ha.

Figure 2.1 Mussel longlines in Killary Harbour, west Coast of Ireland.

2.2.3 Ireland – mussel (bottom)

Bottom mussel production occurs in four bays in Ireland (Lough Swilly, Carlingford Lough, Waterford Harbour, Wexford Harbour and Castlemaine Harbour- Figure 2.1). These areas traditionally utilize this method of culture given the close proximity to the primary source of seed for this practice, i.e. wild subtidal mussel seed beds.

The majority of seed mussel are sourced off the east coast which is regulated (as a fishery) by the Department of Agriculture Food and the Marine. The range of seed size sourced is 15–40 mm but the ideal range is 25–35 mm. Variations in seed quality among the seed beds do exist within years and between years. The quantity of seed available on the east coast varies considerably between years. In poor seed year's, seed intake may be supplemented by rope seed from Ireland or bottom dredged/hand raked seed from UK sites (subject to separate alien species risk assessment).

The stocking density of seed within a bay varies across each producer and is site dependent. At present the seed stocking density ranges from 10–60 t/ha with the average around 30 t/ha. Relaying of seed mussels from the hold is carried out by water jet through holes in the side of vessel. Once relayed it can take from 12–24 months to reach market size but the average is around 18 months. However, the time on the relay plot can depend on the stock level from the previous year, the progression of sales from the previous year's stock, the progression of sales of the current year's stock, the market price and demand and the fluctuations of meat yield levels.

During the on-growing period after relaying of seed, sites can be mopped for starfish and fished for crab (via potting) as a predator control method. Given the nature of the bottom culture of mussels and the reliance on the use of large dredging vessels, licenced areas tend to be larger than other aquaculture production areas. The average size for licenced bottom mussel culture plots in Ireland is 33 ha. The maximum area for a single site is 177 ha.

2.2.4 Ireland – finfish (cages - marine)

While there are 67 licenced marine sites for the production of Atlantic Salmon (*Salmo salar*) in Ireland (Table 2.1), active production in 2020 only occurs at approximately 25 sites (Marine Institute, 2020). There are three distinct regions in Ireland where salmonid farming is carried out: the southwest (Counties Cork and Kerry), the west (Counties Mayo and Galway) and the northwest (Co. Donegal), Figure 2.2. These regions are geographically separate from each other with distances between regions of ca.160 km from northwest to west and ca. 200 km from west to southwest. As with other production systems requiring the use and maintenance of structures in the marine environment locations for finfish culture are selected on the basis of sufficient depth > 20 m, shelter and access to appropriate shore-based facilities, including pier infrastructure. The mean area of licenced marine finfish sites in Ireland is 15.7 ha (0.60 ha–89 ha).

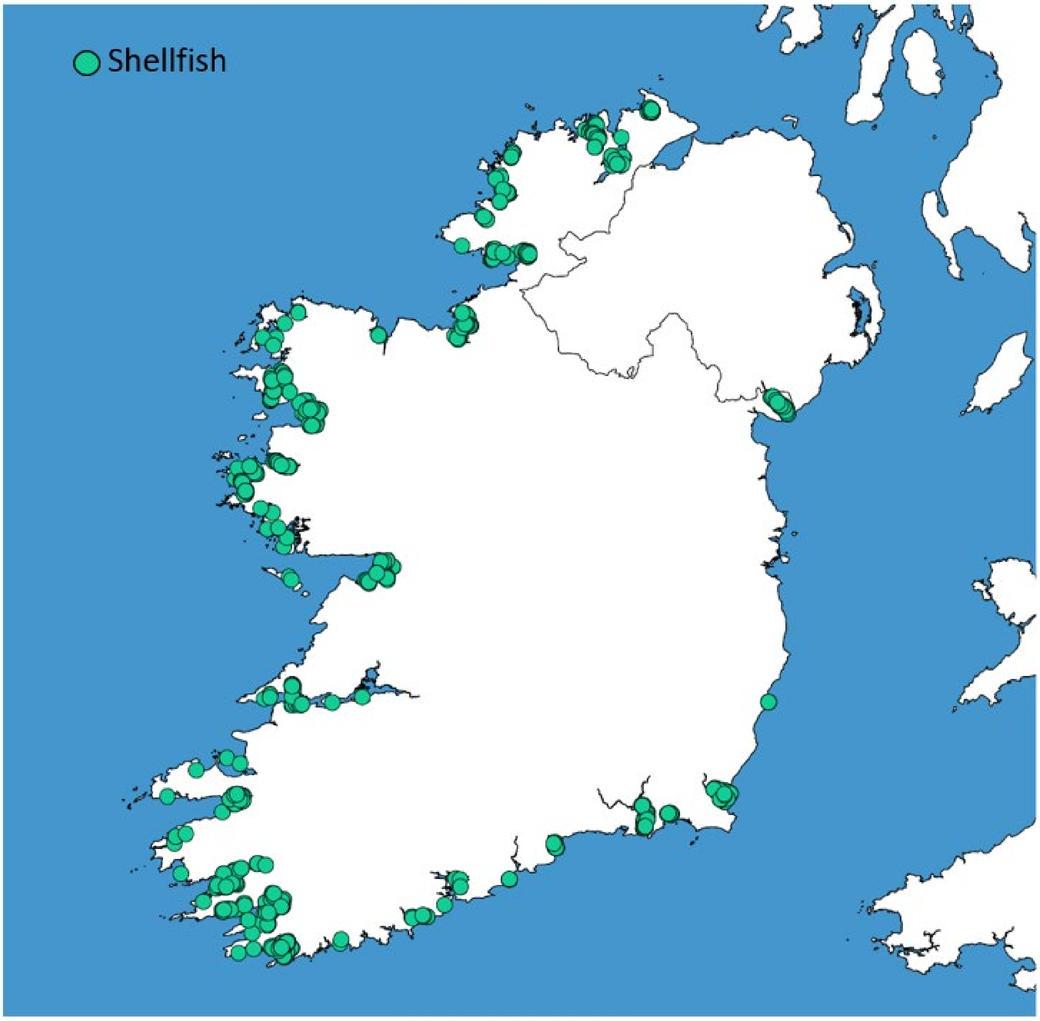

Figure 2.2 Shellfish aquaculture sites around the coast of Ireland.

Open circular net pen cages are typically used in Ireland. The majority of cages are approximately 126 m circumference net pens, with 15 m sides. Cages are arranged in grids which can vary in number from four to 16 cages. Most sites also utilize a feed barge which is moored on site and can hold a maximum of 200 tonnes of feed. The feed barge is designed to feed the stock automatically. The cages also utilize camera systems designed to monitor the fish behaviour, optimize food input and thus, minimize waste.

While some sites are used specifically for culture through various life history stages of salmon (e.g. smolt input and subsequent removal to grower site upon reaching a specific weight), the trend more recently is to carry the full production through at a single site.

It is now recognized that best welfare and environmental practices in salmon farming are aided by the establishment of sufficient farm sites, in a sufficient number of bays and loughs that provides multiple options for site alternation and fallowing, to suit circumstances. Fallowing and rotation are well-established agricultural practices that apply equally to marine salmon farming. Fallowing brings two main benefits:

i. The interruption of disease or infestation cycles by temporary removal of the primary host species, with a consequent reduction in host health issues and veterinary intervention needs.
ii. The ability to vacate sea pens over a farm seabed area, to allow adequate time for the rejuvenation of the seabed, prior to the input of new stock.

It should be noted that the time required to achieve both benefits listed above may not be comparable. The time required to achieve a break in an infection cycle may be considerably shorter than that required for the benthos to recover.

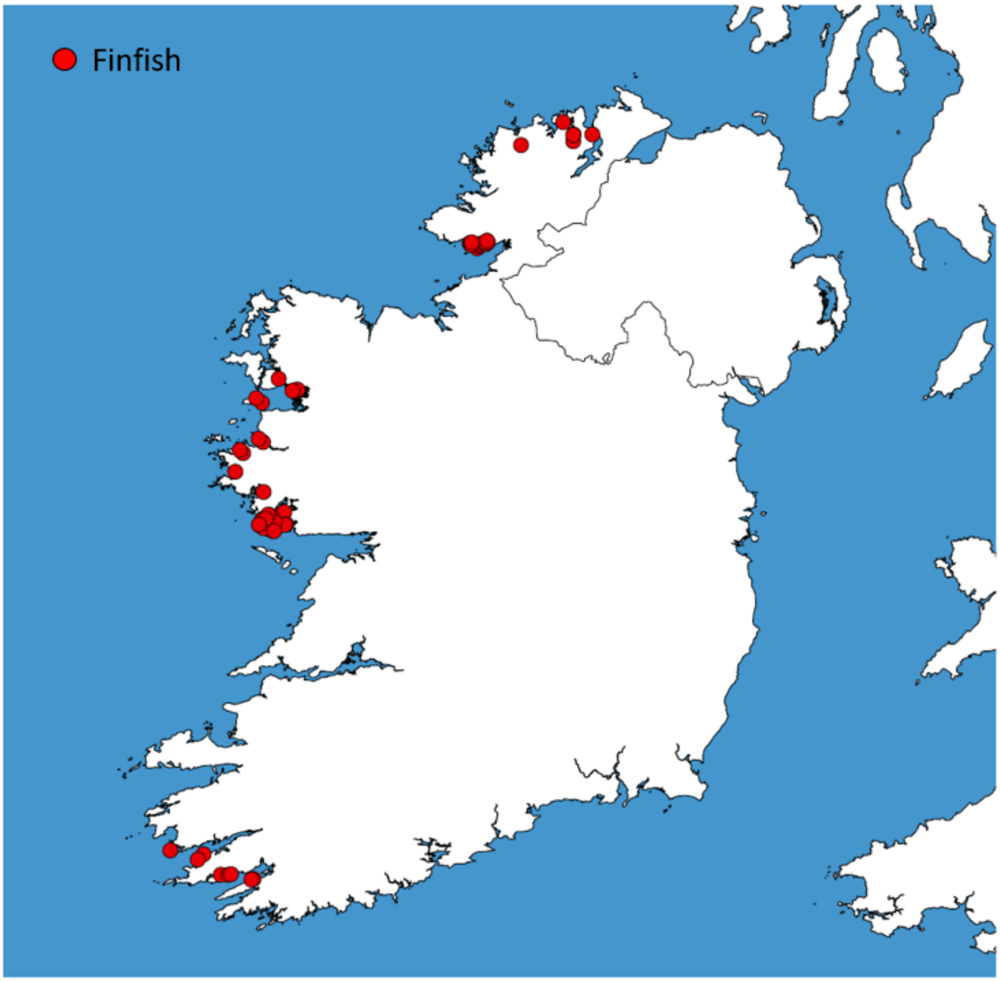

Figure 2.3 Finfish aquaculture sites around the coast of Ireland.

2.2.5 Ireland – seaweed culture

In Ireland, seaweed culture is licenced at 14 sites. Cultivation of seaweeds at sea consists of deployment of seeded ropes that are suspended in subtidal areas. Most operators typically use single header longline structures, similar to mussel longlines (although these longlines generally have two header ropes). The structures comprise an anchorage system, connected to a header rope on or near the surface that is supported by buoys. Longlines can vary slightly between sites and between operators due to different challenges in the deployment, and also in the type and amount of equipment available. The main species cultured is *Alaria esculentia*, known colloquially as winter weed as it is sown in December and harvested the following May. The rapid turnaround makes this culture attractive for most units though other oarweed species and other main groups are cultured also in small amounts. There is increasing interest also in the cultivation of *Laminaria digitata*.

Seaweed plantlets are produced at one hatchery in Bantry Bay and their product, settled onto a specialised collector rope, is then supplied to suspended culture production units. In some sites, operators may rely on the wild settlement of seaweed and selectively harvest on the basis of demand from buyers.

Seaweed aquaculture, as opposed to the wild harvesting sector, remains as a minor component of national aquaculture output; 44 tonnes output in 2020 by 4 production units. The segment is gaining new impetus however, due to increasing EU interest to invest in seaweed aquaculture with several new enterprises in start-up phase, benefitting from new funding initiatives.

2.2.6 Ireland – other species

The Manila clam, *Ruditapes philippinarum,* was first introduced to Ireland as a culture species in 1982 (Drummond et al 2006). Production for this species is concentrated in the Northwest of the Country in close proximity to the sole hatchery producing seed. This species is on-grown in sediment (during both nursery and grow out phases).

Seed is placed on the foreshore in April and held in specially designed wooden frames covered with 1.2 mm mesh. At 8–9 mm the clams are graded and thinned, and these are allowed to grow over summer until by September they have reached 10–12 mm. The young clams are then allowed to overwinter in the frames.

In the second year, when the young clams are 12–14 mm they are ready to plant into specially prepared parks. These areas comprise hard compacted fine sands and are tilled to remove any rock or stones and predatory animals (e.g. crabs or whelks). The year-old clams are transplanted in April at a density of 250 per square metre. The areas are then covered by predator mesh which is maintained to remove seaweed throughout the growing season.

By the end of the second year (April) they grow to 10–12 grammes, at which time they were ideal for the Italian market where clams are eaten small. The end product (20 gramme clams), is usually harvested later in the year. Harvesting is carried by specially modified plows deployed at the back of tractors.

In Ireland, despite there being 21 licences to culture Manila clams (Table 2.1), the production of this species has been heavily hit by the advent of the brown ring disease in production systems. There are currently no operators producing Manila clams in Ireland.

The king scallop, *Pecten maximus* is also farmed in bays in Donegal and Kerry, using a combination of suspended spat collection, lantern nets for juveniles and finished using bottom culture. Harvesting is by diving.

Four shellfish hatcheries, based on the west coast, supply *gigas* oyster seed, mainly diploid stock to local companies. 27.5 million spat units were supplied in 2020. Native oyster and scallop seed are also produced in smaller quantities by these units for local supply. The majority of oyster seed however; mainly triploid stock, needs to be imported from commercial hatcheries of France and Britain, up to 450 million seed units are imported annually. Abalone species are produced and processed in Kilkieran Bay for a range of specialised products by a combined production cycle and processing unit. Urchin culture had been, up to recently, in commercial production in Dunmanus Bay. Suspended for now, it is hoped to recommence production there or in nearby Bantry Bay, within the coming years. The total output volume of hatchery, nursery and combined land-based units was estimated as 30 tonnes in 2020.

Table 2.1 Summary of aquaculture licences in Ireland (as of 31 March 2022). Source DAFM Aquaculture database. (https://dafm-maps.marine.ie/aquaculture-viewer/).

Licenced species (primary)	Marine sites
Salmon	67
Trout	1
Other finfish	
Mussels	
rope	235
bottom	89
Oyster	
Native (*Ostrea edulis*)	30
Pacific Oyster (suspended/Intertidal)	511
Pacific Oyster (bottom)	12
Hatchery	
Clams (*Ruditapes philipinarum*)	21
Scallop (*Pecten maximus*)	24
Other molluscs*	3
Urchins (*Paracentrotus lividus*)	5
Seaweed	14

*other mollusc - abalone, periwinkles - Pacific oyster - *Magallana gigas*

2.3 The UK

The aquaculture industry in the United Kingdom is dominated by the farming of Atlantic salmon (mariculture), which is concentrated in the coastal waters around Scotland. Smaller aquaculture business includes shellfish and seaweed farming in England, Wales and NI. 99% of finfish production is from Scotland, whereas 47% of shellfish production comes from England and Wales. The Centre for Environment, Fisheries and Aquaculture Science (Cefas), has over 500 business registered in England and Wales for finfish aquaculture, though most of these are breeders of fish for ponds and indoor tanks (Public register of Aquaculture Production Businesses in England and Wales (cefas.co.uk)). The second largest aquaculture market in terms of tonnage is the shellfish market, mostly mussels, but oysters and scallops also contribute to these sales figures.

2.4 Northern Ireland

There are 28 active aquaculture producers in Northern Ireland (NI), employing some 130 people. The main shellfish species cultivated are intertidal oysters on trestles and subtidal mussels, with two licensed sites for suspended mussel cultivation (smaller amounts of scallops and Native oysters are also produced, the latter not true aquaculture); and finfish species: marine salmon, freshwater rainbow trout and brown trout. The combined aquaculture industry is valued at approximately 11.6 million GBP (DAERA, 2018). In 2018, the Salmon sector was worth 4.86 million GBP (42% of total sector), Oyster sector 2.97 million GBP (26%), Trout sector 1.9 million GBP (17% of total sector), and Mussel sector 1.84 million GBP (16%).

A shift in the main species cultivated has been observed over the last 5 years, from mussels to Pacific oysters. Mussel production has dropped from 3324 t in 2013 to 2060 t in 2018 (average price per tonne has also dropped from 1730 GBP to 891 GBP). Whilst Pacific oyster production has grown from 138 t in 2013 to 909 t in 2018 (average price per tonne has increased from 2503 GBP to 3278 GBP).

Cultivation methods and species grown

2.4.1 Northern Ireland – oysters trestle (intertidal)

Pacific oysters are grown from spat which is imported from certified hatcheries (in Ireland, France and the UK), spat is placed in bags (pouches) on intertidal trestles (Figure 2.3) and on-grown to harvestable size (2.5–3 years). Oyster site maintenance is required, turning bags to reduce fouling and splitting bags as the oysters grow to maintain good shell shape and growth. Pouches have different sized mesh to allow water (food) flow through the bags, therefore different bags are needed at different stages of grow out. The more detailed description of Irish off-bottom Pacific oyster culture method above is directly relevant to Pacific oyster cultivation in Northern Ireland (NI).

NI oyster producers have trialled a number of different bags: typical flay pouches, deeper rectangular "walled" bags plus the Ortac™ systems with variable success rates. There has also been innovation with attaching the bags to the trestles; including attachment at one long edge with a slight overlap to the next bag, allowing a number of bags to be turned in one go, also attaching floats to allow the bags to flip themselves with the tide. Trials are site dependant and success with novel systems depends on local environmental factors.

At present there are 13 licenced sites for Pacific oyster growth, one of these is also licenced for Native oysters (Figure 2.4). Site areas range from 2.5–51 hectare sites. Stocking density varies between sites and years.

Figure 2.4 Pacific oysters cultivated in bags on trestles in the intertidal area, two specimens of *M. gigas*.

The Lough Foyle oyster fishery is one of the last remaining productive native oyster fisheries in Europe. The fishery has been harvested intensively in the past and efforts to develop its full potential and manage the fishery in a sustainable manner historically failed due to a lack of legislation. In September 2008, the Loughs Agency of the Foyle Carlingford and Irish Lights Commission began to regulate the fishery for the first time. The Agency licenses oyster fishing vessels in Lough Foyle and they are permitted to operate from 19 September–31 March. Regulations allow for postponement of the fishery to give recently settled spat an opportunity to become established and, for example, the 2018/19 season started on 9th October 2018.

The Loughs Agency carry out surveys every autumn and spring. Their results, together with information from the spawning assessment, help to inform management decisions. The dredge survey produces data on oyster numbers, length, weight and mortality, and spat, or juvenile oyster, settlement. The data are used to indicate the number of oysters above the 80 mm minimum landing size which may be available to harvest. It allows a precautionary approach to management to be taken and ensures that an effective spawning stock is maintained.

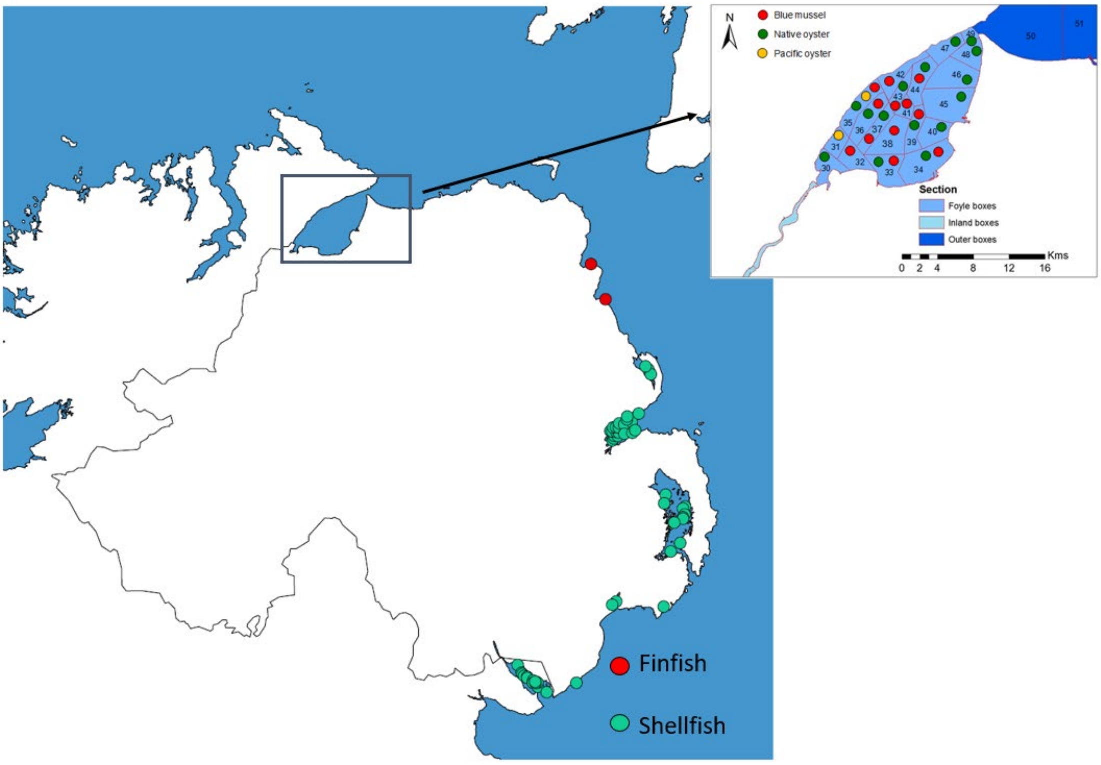

Figure 2.5 Shellfish and finfish aquaculture sites around the coast of Ireland (licenced sites shown here). Insert showing detail of aquaculture activities in Lough Foyle, the most northerly sea lough.

2.4.2 Northern Ireland – mussels (suspended)

One of the seven licenced aquaculture sites for suspended mussel cultivation in Strangford Lough is currently active. At this active site subsurface suspended mussel cultivation takes place, with the ropes suspended from submerged header lines. This system was introduced to reduce the visual impact of rows of barrels floating on the surface. Marker buoys indicate the site area but the system is mostly hidden from view, mussel lines are brought to the surface to maintain and harvest using a special barge. Adjacent to this site there is also suspended longline mussel cultivation, similar to that described in Ireland section above.

2.4.3 Northern Ireland – mussels (bottom cultivated)

Mussels are dredged from offshore naturally occurring seed beds (Amounts collected are controlled by DAERA), seed mussel is relayed (Figure 2.6) on licensed aquaculture sites in the five sea-loughs (Figure 2.5). Maintenance of bottom grown mussel sites includes: consideration of stocking density; thinning out of mussel density and predator control (mopping for starfish and potting for crabs) as required.

The NI mussel production is mainly from bottom cultivation of wild mussel seed. Wild seed is fished from offshore ephemeral wild mussel beds by dredging, this is a controlled fishery and will remain closed if seed is not present in sufficient amounts to allow fishing. Dredged seed (Figure 2.4) is relayed on licensed aquaculture sites in the five sea loughs (Lough Foyle sites are not included on the map, as this is an unregulated fishery due to jurisdictional issues). Site maintenance is required to control against the main predators – mopping of mussel aquaculture sites will reduce starfish and sea urchin predation. Potting for crabs is used in some areas to provide an additional fishery and reduce crab predation. Consideration of stocking density must also be considered, however often this is controlled by availability of seed mussel. Stocking density varies from year-to-year and between sites and loughs. The sheltered waters of the NI sea loughs provide safe, easily accessible aquaculture sites, however declining water quality in these coastal areas has increasingly presented a problem to the industry. Poor water quality can result in poor shellfish quality and site degraded or closed. Areas with high microbiological contamination can be closed and remain closed for extended periods of time to protect public health. This results in an economic loss to industry. Shellfish bed closures, however, do not fully protect human health as they can only be triggered once shellfish testing has taken place. This prompted joint work in the UK to look at "Developing an assurance scheme for shellfish and human health (DASSHH)" looking at a risk-based approach to adaptive management of shellfish classification.

Figure 2.6 Mussel seed, mussel dredge (with mops for predator control) and mussel dredgers.

The impact of the introduction of the non-indigenous Slipper limpet (*Crepidula fornicata*) in Belfast Lough is of interest here. Belfast Lough was the largest bottom cultivated mussel producing area in NI, with export of half-grown mussel to other sea loughs for finishing and to the Netherlands. The discovery of *C. fornicata* changed this activity; producers were no longer allowed to export half grown mussels to finish in other sea loughs or countries.

2.4.4 Northern Ireland – finfish

There are two Salmon farm sites in Northern Irish waters off the North Antrim coast, at Glenarm and Redcastle (Figure 2.4). NI have two marine salmon aquaculture sites operated by the same company, "Glenarm Organic Salmon Ltd". The sites are situated in Glenarm and Red Bay and are laid out in mooring grid formations as described below. Each site has 16 UPVC circular cages collars and hand rails of 22 m Ø suspending a net cage to 15 m depth. Each cage has the potential of producing 50 to 60 tonnes of salmon given optimum conditions. The company does operate ROV's with cameras for a number of functions, mortality assessments, net checking, stock health checks and feeding efficiency estimating pellet fall out at the bottom of the cages. Due to the nature of these sites, which is probably the one of most exposed sites in the British Isles in terms of wind and tides, there are limited options to fallow. With high tidal flows of 3.5 kts top spring, there is very little if any faecal or waste food material on the seabed beneath the cages, therefore fallowing is not entirely necessary (DAERA pers. Comm.). The Company have achieved organic status, the operate with lower stocking densities to fulfil organic status requirements; this may also help to reduce any problems with lice. The salmon smolts are currently sourced in ROI, stocked from November to April and the production cycle ≈12 to 18 months, salmon are then harvested at a desired market size of 3 to 4 kgs average weight. The exposed nature of these sites and strong currents result in no sea lice issues on this farm and therefore, no treatments are required. Lice levels are monitored monthly by the Department of Agriculture, Environment and Rural Affairs (DAERA unpublished).

2.4.5 Northern Ireland – seaweed

There are two seaweed farms licenced, the trial seaweed operation in Strangford Lough was established and maintained by Queen's University Belfast, this operation is not currently in production.

One commercial seaweed farm is licenced of Rathlin Island, growing kelp on longlines in a similar fashion as described in the Ireland section above. The kelp is used as an additive in a range of foodstuffs. Kelp plantlets are sourced from the companies own nursery system.

Ireland and NI have a long history of seaweed harvesting, and larger scale harvesting operations exist but these have not been classed as marine aquaculture at this time.

2.4.6 Northern Ireland – other species

King Scallop aquaculture had been trialed in a number of locations in Strangford Lough, restrictions on harvesting practices with only permits for diving to harvest has impacted the expansion of this activity. There are also a number of fishery orders for wild scallop harvesting. There are several wild cockle and winkle fisheries, they are not detailed here however it is worth noting that there is one licensed area to farm periwinkles.

2.5 Scotland

A number of shellfish are farmed in Scotland; mussels (*Mytilus species*), Pacific oysters (*Magallana gigas*), native oysters (*Ostrea edulis*), scallops (*Pecten maximus*) and queen scallops (*Aequipecten opercularis*) (Figure 2.7). In 2020 there were 125 authorized and active shellfish businesses in operation (Table 2.2) and 142 people employed full-time with a further 158 part-time and casual workers (Munro, 2021). Of these, 10 businesses produced nearly 80% of total mussel production in Scotland, whereas 4 businesses are responsible for more than 70% of Pacific oyster production (Munro 2021). Total value of the sector in 2020 was approximately 6.1 million GBP, although it should be noted that this was a considerable decrease from 2019 when the sector was worth approximately 7.9 million GBP (Munro, 2021). There are several reasons for this decline, which include lost trade due to the Covid-19 pandemic as well as Brexit. Due to these complexities, it is difficult to use the historic trends to estimate near-future production levels at present, but whilst absolute values are difficult to predict, it is likely that the proportion of total production from each species will remain relatively similar. Mussels (*Mytilus* spp.) are by far the most valuable part of the sector with 2020 table trade valued at 5 million GBP, followed by Pacific oysters at 970,000 GBP, native oysters at 50,000 GBP scallops at 40,000 GBP and Queen scallops are negligible value (Munro, 2021).

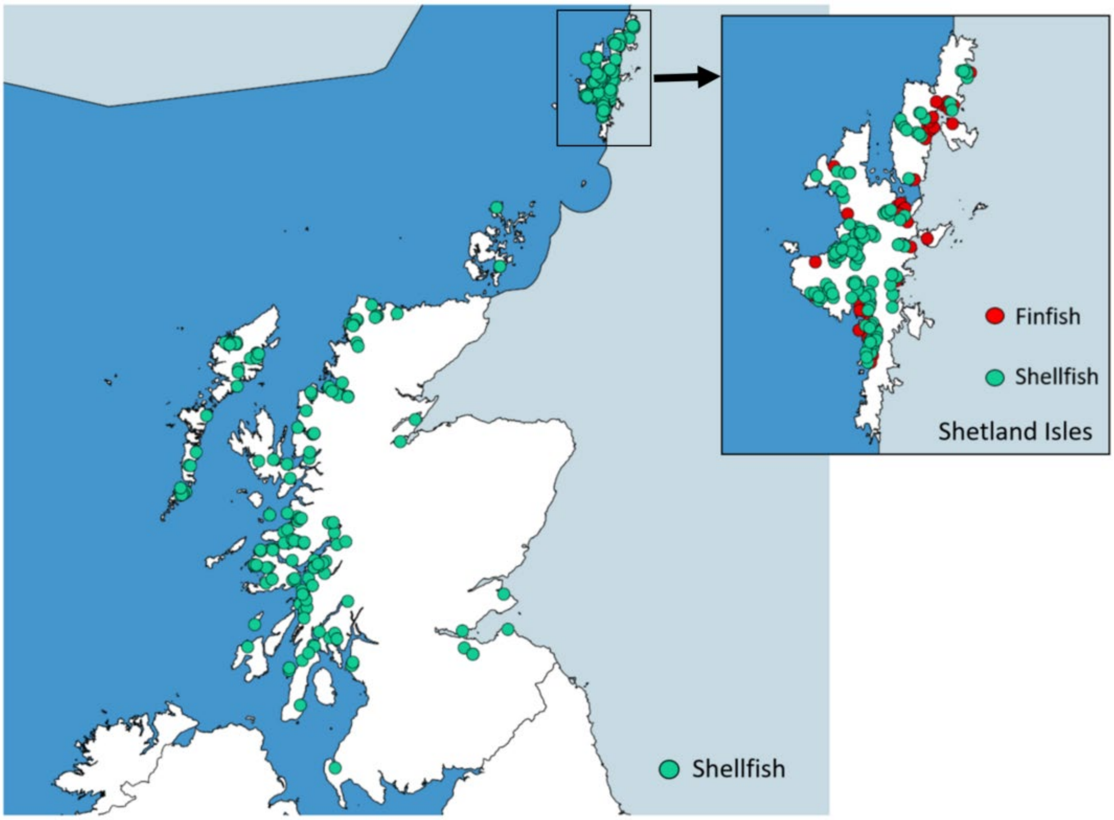

Figure 2.7 Shellfish aquaculture sites around the coast of Scotland. Insert shows detail of both shellfish and finfish farms on the Shetland Isles.

Table 2.2 Authorized and active farmed shellfish businesses (https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2021/06/scottish-shellfish-farm-production-survey-2020/documents/scottish-shellfish-farm-production-survey-2020/scottish-shellfish-farm-production-survey-2020/).

	Number of Businesses									
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Active	153	153	142	144	144	138	132	130	129	125

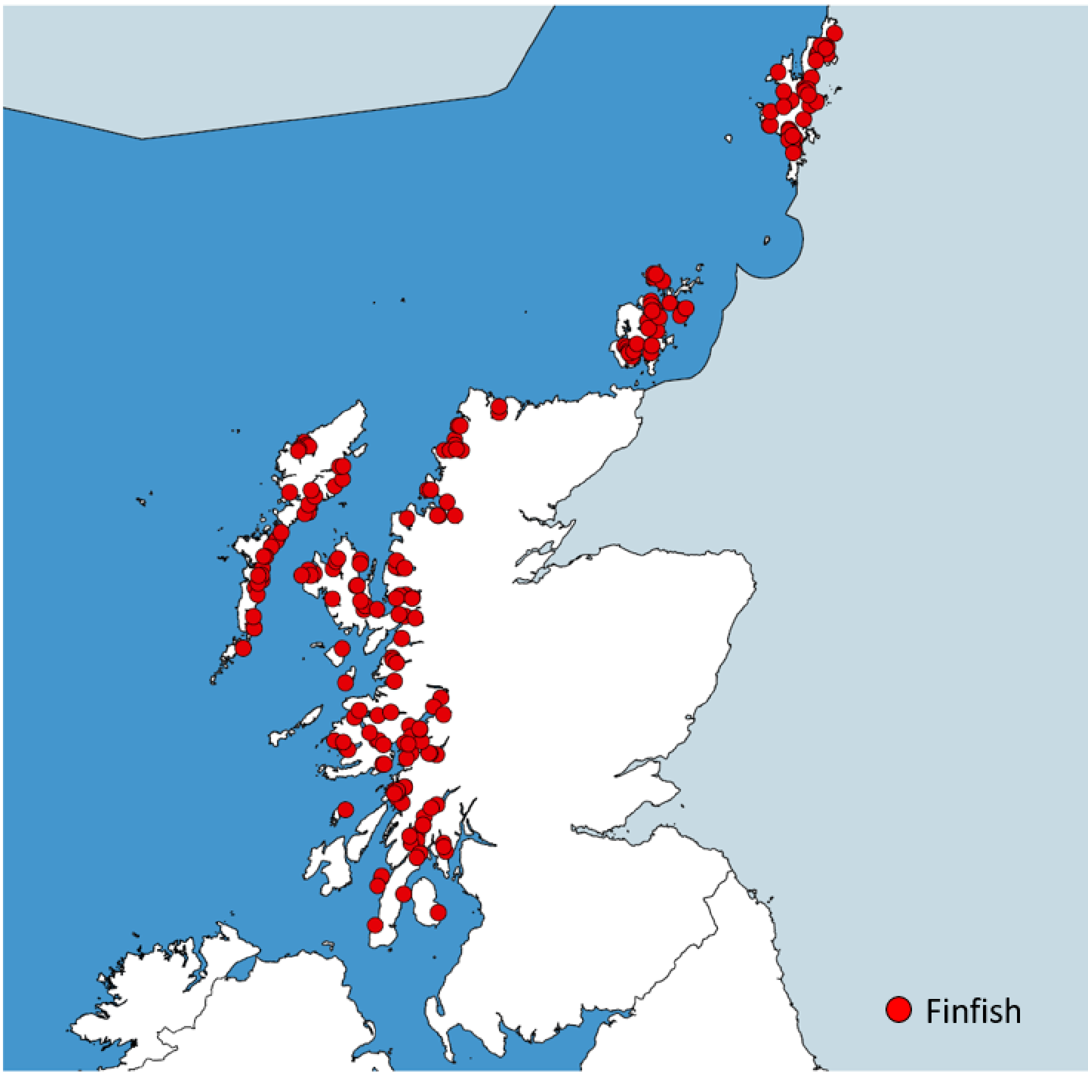

Figure 2.8 Finfish marine aquaculture sites around the coast of Scotland.

2.5.1 Scotland – oyster trestle (intertidal)

Intertidal off-bottom trestle cultivation of Pacific oysters relies primarily on spat sourced in France and UK, on-grown in flat bags or in the circular hanging bag systems. Maintenance and husbandry as described for Ireland. There are several well-established oyster hatcheries throughout the UK that oyster farmers in Scotland can use to source juveniles (see Guernsey).

Native oysters are farmed at a few sites using hanging basket system, suspended from off-bottom trestles (J. Brown, pers. comm.). Natural spat settlement will also maintain naturally occurring native oyster beds.

2.5.2 Scotland – mussel (suspension- rope)

Most mussel sites rely on suspended culture, with mussels grown on longlines (Natural Scotland, 2022) as per Ireland above. Mussel producers have reported poor spat settlement and mortality over the last decade (Munro, 2021). This has led to investment in research and innovation projects aimed at improving spat, including work to develop Scotland's first commercial mussel hatchery which aims to provide a more consistent source of spat. However, for the time being, the Scottish mussel industry are still reliant on wild spat. Longline suspended mussel cultivation similar to that described in the Irish suspended mussel section.

It is important to note that length of the production cycle is highly dependent on the site conditions. Furthermore, depending on the area, farmed shellfish often undergo depuration following harvesting to ensure they are safe for human consumption (Scott et al., 2010).

2.5.3 Scotland – mussel (bottom)

No bottom cultivation of mussels reported.

2.5.4 Scotland – finfish (cages- marine)

Atlantic salmon (*Salmo salar*) is an anadromous fish and farming involves both a freshwater and a marine phase. In Scotland, following the hatchery stage, juveniles are grown in freshwater tanks or freshwater cages before being transferred to sea cages. In 2020, there were 24 companies and 78 sites used in freshwater production of Atlantic salmon, whereas there were 11 companies and 232 sites (although only 8 companies and 131 sites were actively producing) used in marine production (Munro et al., 2020). There are a range of reasons why not all companies and sites are actively producing, but one of the main reasons is that some sites will be fallow to break disease cycles. This is common practice in salmon farming and in Scotland can range from 12 months to 2 years (Munro et al., 2021). Some companies are involved in both freshwater and marine production. Regarding final product, 6 companies produce 99% of farmed salmon in Scotland (Munro et al., 2020). In 2020, approximately 1630 people were involved in seawater production (not including processing or marketing activities, this included 1557 full time staff and 73 part time staff (Munro et al., 2021). Though there is interest in developing land-based Recirculating Aquaculture Systems (RAS) for salmon, growout still takes place in sea cages with only a small amount of seawater tanks used for salmon broodstock or to produce other species, e.g halibut (Munro, 2021). The seawater cage farms can be found throughout the west coast and highlands and islands. At present, there is a licencing moratorium on future expansion of salmonid farms on the north and east coasts.

Rainbow trout is another species that is also farmed in the Scottish marine environment. There are up to 21 companies involved in rainbow trout aquaculture, with about 50 freshwater and marine sites in total (producing 7500 tonnes in total in 2020), with seawater cages (from 9 sites) representing approximately 55% of production (Munro, 2021). Other fish species produced at a smaller scale include brown/sea trout (*Salmo trutta*) and halibut (*Hippoglossus hippoglossus*). Lumpsucker (*Cyclopterus lumpus*) and wrasse species (*Labridae)* are grown for use as biological controls of sea lice levels in salmon sea cages. Approximately 22 full time staff and 13 part-time staff are involved in the farming of these 'other' fish species, which total about 43 tonnes of production, however it is important to note that due to the small number of companies involved the farm survey results are not as detailed as Atlantic salmon and rainbow trout in order to protect commercial confidentiality (Munro, 2021).

2.5.5 Scotland – seaweed

As an emerging sector, it is difficult to provide an overview of the Scottish seaweed sector and data are not routinely provided as with fish and shellfish farms. Scotland has a long history of wild seaweed harvesting, but seaweed aquaculture is more recent and still emerging (Table 2.4). It is estimated that there are less than 10 commercial seaweed farms at present, and overall aquaculture production is still low. However, it was estimated that in 2020 seaweed-based industry in Scotland (as a whole) had a turnover of £4 million per year and an estimated gross value added (GVA) of 510,000 GBP and employed 59 people, therefore there is strong interest in developing a Scottish seaweed aquaculture sector (ABPmer and RPA, 2022). One of the bottlenecks for the development of seaweed aquaculture in Scotland has been the lack of appropriate regulatory frameworks. In 2017 the Scottish Government produced the Seaweed Policy Statement that outlined support for small to medium scale farms (≤50 x 200 m longlines), providing all planning requirements are met (Scottish Government, 2017). The Seaweed Cultivation Policy Statement (SCPS) has been informed through consultation in 2013 with various public bodies with an interest in seaweed cultivation and harvesting, including the Food Standards Agency in Scotland, the Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH), Historic Scotland (HS), and The Crown Estate. A consultation report www.scotland.gov.uk/publications/2014/11/5316 and Strategic Environmental Assessment (SEA) Environmental Report www.gov.scot/publications/2013/08/6786/0 were also completed.

2.5.6 Scotland – other shellfish

Native oysters (*Ostrea edulis*), scallops (*Pecten maximus*) and queen scallops (*Aequipecten opercularis*) are cultured to lesser degrees. In addition, there are also some crustacean farms, mainly hatchery/research units. The shellfish points on the map near Edinburgh (east coast) are for crustaceans rather than bivalves, there are no bivalve farms on the east coast, except those in the Cromarty firth (north).

Scallops have been cultivated until quite recently in Scotland but limited by lack of seed supply. An increasing interest in marine restoration projects has led to establishment of new hatcheries for example in Orkney and Portsmouth, which may improve seed availability and facilitate scallop farming (Sustainable Scallop Hatchery – Ocean Conservation Trust) (J. Brown, The Grower, pers. Comm.).

2.6 Wales

Information describing marine aquaculture activities around the coastline of England and Wales is frequently presented jointly, thus complicating the data gathering process. Hence England and Wales marine aquaculture (plus some related activities) are presented together on the maps (Figure 2.9 and Figure 2.10).

Cultivation methods and species grown in Wales

Currently in North Wales and Menai there are 5 shellfish farms, mussels and pacific oysters. In South Wales there are 6 mussel farms.

There are long-running efforts to get old leases replaced, including in Menai Strait (west), this would result in resumption of production in two oyster farms and two mussel farms. Menai Strait (west) may be underway again soon.

2.6.1 Wales – oyster trestle (intertidal)

The Pacific oyster, *Magallana gigas* is cultivated in Wales using intertidal off-bottom culture methods with trestles and bags. The culture of oysters is located predominantly in sheltered areas along the coast of Wales (Figure 2.9). Intertidal off-bottom oyster cultivation in Wales is similar to that described in Ireland.

There is one oyster farm in north Wales, in the western Menai Strait, in South Wales shellfish production includes Pacific and native oysters in Pembrokeshire (Home - Atlantic Edge Oysters).

A native oyster hatchery is under construction at Bangor University to support a restoration programme (The Wales Native Oyster Restoration Project – Native Oyster Network).

2.6.2 Wales – mussel (suspension- rope)

An experimental offshore mussel longline system is operating in Conwy Bay just to the East of Anglesey. In South Wales shellfish production includes longline mussel production in Swansea Dock plus offshore test system for longline mussels.

2.6.3 Wales – mussel (bottom)

In north Wales, farming is predominantly blue mussel farming, by weight and value, with ground laying of spat in the eastern Menai Strait. Bottom mussel production typically occurs in sheltered bays in Wales (Figure 2.9), this traditionally culture method is used due to the site's close proximity to the primary source of seed for this practice, i.e. wild subtidal seed beds.

Table 2.3 Shellfish data extracted from Classification zone maps for Shellfish areas in England and Wales (Classification zone maps - Cefas (Centre for Environment, Fisheries and Aquaculture Science)).

Classification Zone for Species	Number of zones
Mussel spp.	**31**
Mussel (longline)	**1**
M.gigas	**34**
O.edulis	**18**
C.edule	**18**
M.mercenaria	**10**
P.maximus	**2**
Tapes spp.	**5**
Mimachlamys varia	**2**
Ensis spp.	**4**
Spisula spp.	**1**
All species	**3**

2.6.4 Wales – finfish (cages- marine)

There is no marine finfish production in sea cages. Figure 2.10 shows the location of marine related activities, using marine water for the cleaner fish hatcheries. Lumpfish are cultivated from eggs imported from Iceland and Norway and reared for the Scottish salmon cages.

2.6.5 Wales – seaweed culture

Seaweed cultivation is often associated with existing shellfish farms. Table 2.4 provides a summary of seaweed farms in the Celtic Seas ecoregion and includes sites in England and Wales (compiled by E. Cappuzzo).

Car-y-Mor in Wales (Car-y-Mor | ocean farming | nature based solutions | Carbon Copy) is one of the first seaweed and shellfish farms (oysters), it follows the GreenWave model (Maine, USA) which helps train and support ocean farmers (Car-y-Mor | ocean farming | nature based solutions | Carbon Copy).

2.6.6 Wales – other shellfish

Other shellfish are harvested from wild populations that are found beside mussel and oyster farms, these include cockles (*C. edule*).

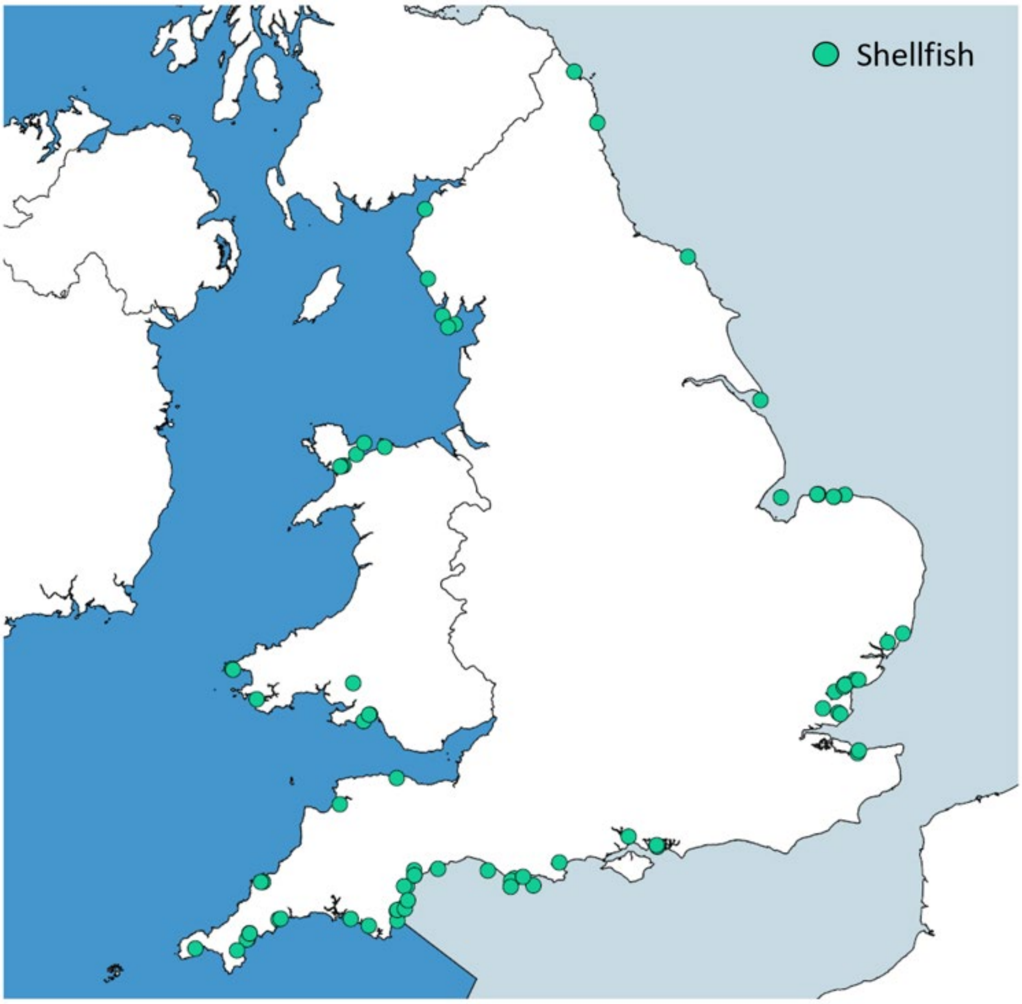

Figure 2.9 Shellfish aquaculture sites around the coast of England and Wales.

Table 2.4 Seaweed farms in the UK

Seaweed Company Name	Company website	Commercial / R&D	country	Location	Comment
The Cornish Seaweed Comp	The Cornish Seaweed Company - organic edible seaweed from Cornwall	Commercial	England	Porthallow Cove - Cornwall	Active - co-located at shellfish aquaculture site owned by WestCountry Mussels of Fowey
Biome Algae	Seaweed Devon Cornwall | Biome Algae	Commercial	England	St Austel Bay - Cornwall	Active - co-located at shellfish aquaculture site owned by WestCountry Mussels of Fowey
Jurassic Sea Farms	Seaweed Farm | Jurassic Sea Farms | Dorset	Commercial	England	Portland Harbour - Dorset	Active - they also farm shellfish bivalve at the same site
Green Ocean Farming	Green Ocean Farming - Global Seaweed Farming	Commercial	England	Portland Harbour - Dorset	Licence granted end of 2021 - unclear whether farm is already active
Green Ocean Farming	Green Ocean Farming - Global Seaweed Farming	Commercial	England	Torbay - Devon	Licence granted end of 2021 - unclear whether farm is already active
SeaGrown	SeaGrown	Commercial	England	Scarborough - Yorkshire	Active
Car-y-Mor	Câr-Y-Môr (carymor.wales)	Commercial	Wales	St David's - Pembrokshire	Active - this is a Community Benefit Society - they also farm shellfish co-located with seaweed
Seaweedology Ltd		Commercial	Wales	? - Pembrokshire	Licence granted end of 2021 - unclear whether farm is already active
Aird Fada	Aird Fada Seaweed Farm : South West Mull and Iona Development | Community Led Sustainable Solutions (swmid.co.uk)	Commercial	Scotland	Loch Scridain - Isle of Mull	Active - this is community-owned - SWMID South West Mull & Iona Development
KelpCrofting	KelpCrofting	Commercial	Scotland	Pabay & Scalpay - Isle of Skye	Active - 2 sites around Isle of Skye
Shore / New Wave Foods	Shore Seaweed - Snacks and Pestos - Healthy, Sustainable, Tasty	Commercial	Scotland	southern end of Kerrera Sound	Active? - different documents indicate they are farming
Sea02 Ltd		Commercial	Scotland	Loch Erisort - Isle of Lewis	Licence granted - unclear whether farm is already active
Argyll Aquaculture		Commercial	Scotland	East Balvicar Bay - Seil Island	Licence granted - unclear whether farm is already active - also they are licence consultant so unclear whether they granted licence for someone else
SAMS	Seaweed farms — Scottish Association for Marine Science, Oban UK (sams.ac.uk)	R&D	Scotland	Kerrera & Port A' Bhuiltin - Argyll	Active - 2 sites for R&D
Islander Kelp	Home - Islander Kelp - Rathlin Island	Commercial	Northern Ireland	Rathlin Island	Active
Queen's University Belfast	Seaweed Research | Queen's University Marine Laboratory (qub.ac.uk)	R&D	Northern Ireland	Strangford Lough	Not Active at present

2.7 England

The main species cultivated on marine sites around the coast of England are mussels and oysters, mainly through bottom cultivation and trestle (or rack and bag) respectively. There are also fisheries for native oysters, cockles and clams (Table 2.3).

One of the main aquaculture areas focused on at present in England is positioned on the south coast, Dorset and East Devon – with potential to contribute significantly to the growth in English marine aquaculture envisaged under the Seafood 2040 strategic framework for England. Aquaculture within this region is developing rapidly with a diverse array of species and techniques either in place or undergoing development both on and offshore. The potential offered by the region for the expansion of aquaculture has recently been recognized by the Department of International Trade (DIT) who have awarded the region status as a High Potential Opportunity (HPO) zone for sustainable aquaculture.

Funded by the Dorset and East Devon Fisheries Local Action Group (FLAG), a comprehensive spatial analysis has been undertaken for the Dorset and East Devon coastal waters of a wide range of marine aquaculture species and techniques. This mapping exercise, together with stakeholder consultation, provides a system to identify optimum locations for new operations and the expansion or diversification of existing farms.

Cultivation methods and species grown

2.7.1 England – oyster trestle (intertidal)

Pacific oysters are cultivated on trestles in the way described above for Irish oysters above. However, subtidal stacked trestle-like systems have also been used for pacific oyster cultivation. There are 18 classification zones for native oysters, wild populations can be harvested from these areas usually from deeper water by boat.

2.7.1.1 England – Pacific oyster (bottom)

In English marine waters there is a category for the bottom culture of Pacific oysters. Wild populations of Pacific oysters have become established in a number of deeper water estuaries particularly off the East and South coast (M. Gubbins, Cefas pers. comm.). Wild populations are also established in some intertidal areas. Recruitment to these wild beds is from natural spat settlement and this resource is classified and can be harvested. Some mapping of these wild populations is available from Cefas. There are also areas of seabed leased to farm pacific oysters grown on the seabed. For example, in Poole Harbour 51 hectares of shellfish beds are leased for the purpose of farming Pacific oysters. Small, hatchery produced seed are reared in the floating nursery system to 10 grammes and once laid on the seabed take approximately 9 months to reach harvest size. Up to 3 million oysters are harvested per year, ca. 400 tons, with 30% sold either locally or in the wider UK market. The majority are sold in the Far East, with Hong Kong and China as the primary markets.

2.7.2 England – mussel (suspension- rope)

There are 2 longline mussel farms, one off the coast of Cornwall (St. Austell) and the other in Lyme Bay. Following successful pilot trials in 2014-2015 the Lyme Bay farm is currently being expanded to its full permitted area. The development will eventually be the largest of its type in

European waters and will use specially designed technology to cultivate the blue mussel, *Mytilus edulis*, on suspended ropes at three sites between 3 and 6 miles offshore. It is expected when fully operational that the three sites will cover a total area of 15.4 square km and produce up to 10,000 tonnes per year once fully developed. Advantages include space and improved water quality. Co-culture of other shellfish species and seaweed cultivation is anticipated.

2.7.2.1 England – mussel (bottom)

The majority of mussel cultivation is bottom/ seabed culture, with seed mussel being fished from local wild seed beds and relayed on licenced aquaculture sites. Bottom mussels are harvested by dredging, raking and by hand in the different areas.

2.7.3 England – finfish (cages- marine)

No marine cage finfish culture.

Marine related finfish activities are mainly land-based but extract seawater for the tanks. There are 3 cleaner fish hatchery sites (Figure 2.10), one on Anglesey (Wales), one in South Wales and one in Portland, Dorset. Onshore, there is Recirculating Aquaculture System (RAS) production of lumpfish for use as cleaner fish in the Scottish salmon sector.

The additional marine related sites shown in Figure 2.10 are wild-caught Wrasse holding tanks, again not strictly speaking aquaculture, as they are wild fish but are destined to be used in aquaculture. The Wrasse are supplied as cleaner fish for the Salmon cages (M. Gubbins, Cefas pers. comm.).

2.7.4 England – seaweed

Table 2.4 shows all of the seaweed farms in the UK at present, this is a fast-expanding sector and will require constant updating. There is also wild harvesting of seaweed which is regulated but is not considered aquaculture. The links in Table 2.4 show general locations of the seaweed sites. Table 2.4 is based on expert knowledge (E. Capuzzo, pers. comm.) and cross-checked with marine licence registers for England, Wales, NI and Scotland showing details for 14 commercial seaweed farms + 3 research and development sites. The commercial farms should all have a granted licence, this report has not included applications currently going through licensing process approval.

2.7.5 England – other shellfish

Wild capture of cockles (*C. edule*), Tapes spp. (mainly Manila clams that were farmed and have now formed wild populations), *Mimachlamys* varia, *Ensis* spp., *M. mercenaria* and *Spisula* spp. from adjacent zones to mussel and Pacific oyster farms.

There is a native oyster hatchery in Morecambe Bay where stock is produced in a land-based facility for on-growing at marine sites for aquaculture and oyster restoration projects. The hatchery also produces Pacific oyster seed.

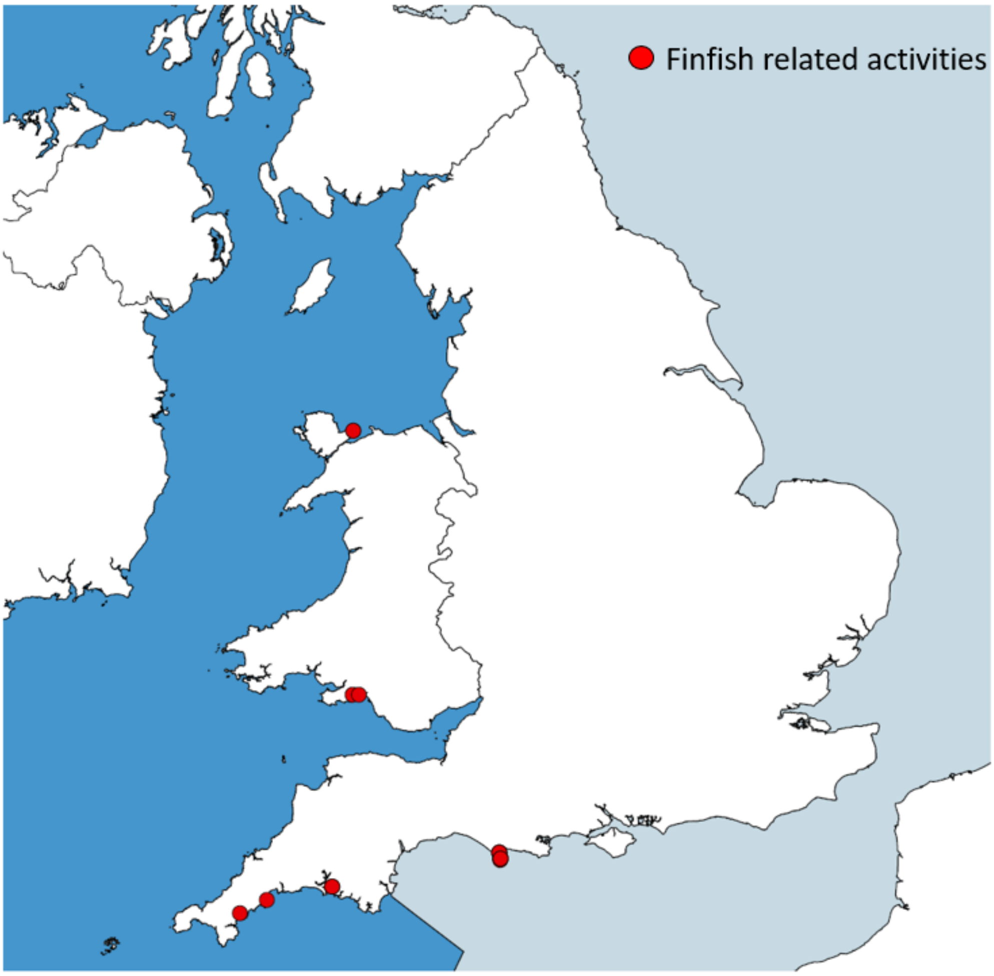

Figure 2.1 Finfish related activities around the coast of England and Wales – not marine cages, related marine aquaculture activities (lumpfish hatcheries and wild-caught Wrasse holding sites).

2.8 Channel Islands

2.8.1 Jersey – oyster trestle (intertidal)

Annual Pacific oyster production from Jersey Oyster farm is equivalent to the rest of Great Britain. Off-bottom, trestle and bag aquaculture support an annual production of over 1000 tonnes of oysters sold throughout the year to France and the UK (M. Gubbins Cefas, pers. comm.).

The oysters are harvested from the Royal Bay of Grouville, on the east coast of Jersey. There are four main areas and two holding areas. The main growing area cover approximately 35 hectares in total, and this is where the majority of the oysters are grown and stored. The holding areas are smaller sites closer to shore. The oysters spend at least half the day exposed when the tide is out to "harden" them off. Size grading, re-bagging, purification and packing is carried out locally (Mussels – Jersey Oyster).

2.8.2 Jersey – mussel ("Bouchot")

A single company cultivates mussels on five hectares of beach area in the Royal Bay of Grouville. The mussels are grown from seed on wooden poles (Bouchot), a method commonly practiced in Brittany and Normandy, France. During September, mussel seed is bought from Ireland where it has been settled onto ropes. These ropes are wound in spirals around the poles. The mussels are ready for harvest in April and May each year. The mussels are harvested using a barge. The primary market is France.

2.8.3 Guernsey

On Guernsey there is one established oyster hatchery that has produced Pacific oyster seed for over 35 years. Pacific oysters are also grown out here using bag and trestle system outlined above.

2.9 Conclusions

In terms of operations, Salmon farms dominate marine aquaculture in Scotland, whilst shellfish dominate in Ireland and the rest of the UK. This may reflect the government funded support provided in these countries to develop the industry. It will be influenced by other users of these marine areas and the multiple uses and stakeholders, emphasizing the importance of the inclusion of aquaculture in marine planning.

The inconsistency of the use of marine aquaculture in the different regions complicated the search for information, making data gathering difficult.

Collation of information for this chapter highlights many gaps in access to high-level evidence of marine aquaculture. Information is either missing or not fully represented. While this chapter aimed to present information for each of the regions and the main species, this was no simple task and reversion to personal communication with local experts yielded the best knowledge. It is useful to note that the countries report and record aquaculture in different ways. The challenges encountered writing this chapter demonstrate the challenge in pulling together a report covering different countries for aquaculture compared to fisheries. Where information was publicly available, references and links have been provided, however much of this information relied on direct knowledge exchange with regional experts.

3 Production over time – Ireland, United Kingdom and Crown Dependencies

3.1 Data sources and gaps

There are various published and unpublished sources of aquaculture statistics for countries within this region, i.e. Republic of Ireland (Ireland), the UK, and the Crown Dependencies of the Isle of Man, Jersey and Guernsey (Table 3.1). In this chapter, the FAO database FishStatJ (FAO, 2022) has been used as the primary source: it provides accessible, comparable, readily extracted statistical time-series (1950–2020) for the annual volume (tonnes live weight) of on-grown product harvested from seawater. These FAO statistics are available for all areas, apart from the Isle of Man for which production statistics are not published, possibly due to confidentiality associated with a limited number of producers. A different EU database (EuroStat, 2022) has been used as an additional source for other production statistics, but does not include the Crown Dependencies, nor the UK post Brexit.

UK aquaculture statistics represent combined figures for Northern Ireland, Scotland, England and Wales. Within the UK, the competent authorities for aquatic animal health (DAERA-NI in Northern Ireland, MSS in Scotland, Cefas in England and Wales) collect production data from ongrowing farms (tonnes live weight) and hatcheries/nurseries (numbers of individuals). Although separate time-series of various aquaculture statistics are published for Scotland, for other nations of the UK these need to be constructed and interpreted using a range of published and unpublished sources (Table 3.1). There are also gaps in statistics due to lack of data collection / collation (e.g. the emerging seaweed segment across the UK), omissions due to confidentiality (when there is a limited numbers of producers), and exclusion of non-food species from databases (EuroStat, 2018). There is also believed to be a regional gap in data collection for mollusc farms in Loch Foyle, due to a lack of regulation associated with uncertainty on the border between Ireland and Northern Ireland (Northern_Ireland_Assembly, 2021). Furthermore, some anomalous figures within international databases are evidently erroneous, and recent figures appear to be estimates (i.e. 2020=2019) likely because up-to-date figures were unavailable when reporting was due.

Production statistics are fundamental evidence of research, policy, regulation and planning, with robust time-series being vital for projecting realistic targets for government and industry plans, and for monitoring progress. It is recommended that existing production statistics are improved by: plugging gaps, correcting errors, and improving timeliness, geographical breakdown and accessibility.

Taxonomic group	Statistics on	Ireland	United Kingdom	Northern Ireland	Scotland	England & Wales	Isle of Man	Channel Islands
Finfish	On-grown production	(EuroStat, 2022; FAO, 2022)	(EuroStat, 2022; FAO, 2022)	SNA (Confidential)	(Scottish Government, 2022, 2021a)	(Cefas, 2015a; Cefas FHI, n.d.; Ellis et al., 2015)	-	(FAO, 2022)
	Hatchery production	(EuroStat, 2022)	(EuroStat, 2022)	(Cefas, 2015a; DAERA-NI, n.d.; Ellis et al., 2015)	(Scottish Government, 2022, 2021a)	(Cefas, 2015a; Cefas FHI, n.d.; Ellis et al., 2015)	SNA	SNA
	Wild prodn input	(EuroStat, 2022)	(EuroStat, 2022)	-	(Salmon_Scotland, 2021)	(Cefas FHI, n.d.)	-	-
Molluscs	On-grown production	(EuroStat, 2022; FAO, 2022)	(EuroStat, 2022; FAO, 2022)	(DAERA-NI, n.d.; Ellis et al., 2015)	(Scottish Government, 2022, 2021b)	(Cefas, 2015b; Cefas FHI, n.d.; Ellis et al., 2015)	-	(FAO, 2022)
	Hatchery production	(EuroStat, 2022)	(EuroStat, 2022)	-	SNA	SNA (Confidential)	-	SNA (Confidential)
	Wild prodn input	(EuroStat, 2022)	(EuroStat, 2022)	(DAERA-NI, n.d.)	-	SNA	-	SNA
Crustaceans	On-grown production	-	(EuroStat, 2022; FAO, 2022)	-	-	(Ellis et al., 2015)	-	-
	Hatchery production	-	(EuroStat, 2022; FAO, 2022)	-	SNA	(Cefas FHI, n.d.)	-	-
Other marine invertebrates		(EuroStat, 2022; FAO, 2022)	SNA	-	-	SNA		-
Seawater plants		(EuroStat, 2022; FAO, 2022)	SNA	SNA	SNA	SNA		SNA

Table 3.1: Potential sources of aquaculture production statistics for Ireland, UK, Northern Ireland, Scotland, England & Wales, the Isle of Man, and Channel Islands. "-" = no relevant aquaculture activity; "SNA" = Statistics Not Availa

3.2 Total production over time

Between 1950 and 2020, production of 27 species (or taxonomic groupings) of finfish, mollusc, crustacean, other invertebrate and seaweed, has been reported across the region. Initially only mollusc production was reported: mussels (*Mytilus* spp.) followed in the 1960s by European flat oyster *Ostrea edulis* and Pacific cupped oyster *Magallana gigas (=Crassostrea gigas)*. Finfish production was first reported in the 1970s with Atlantic salmon *Salmo salar*, followed by rainbow trout *Oncorhynchus mykiss* and then other marine fish species. For both finfish and molluscs, the number of species reported annually has increased until 2011 but subsequently decreased (Fig 3.1A). Bivalve molluscs dominated production volume until the late 1980s, after which finfish have formed the bulk of production (Fig 3.1B): due to Atlantic salmon which currently (2019/2020) comprises > 80% of the regions' aquaculture production volume. Although several species of crustacean, other invertebrate and seaweed have also been reported since 2001 (Fig 3.1A), relative volumes have been insignificant compared with finfish and bivalves (Fig 3.1B). Total aquaculture production increased up to 2004, but has since been static, fluctuating around 240,000 tpa (Fig 3.1B).

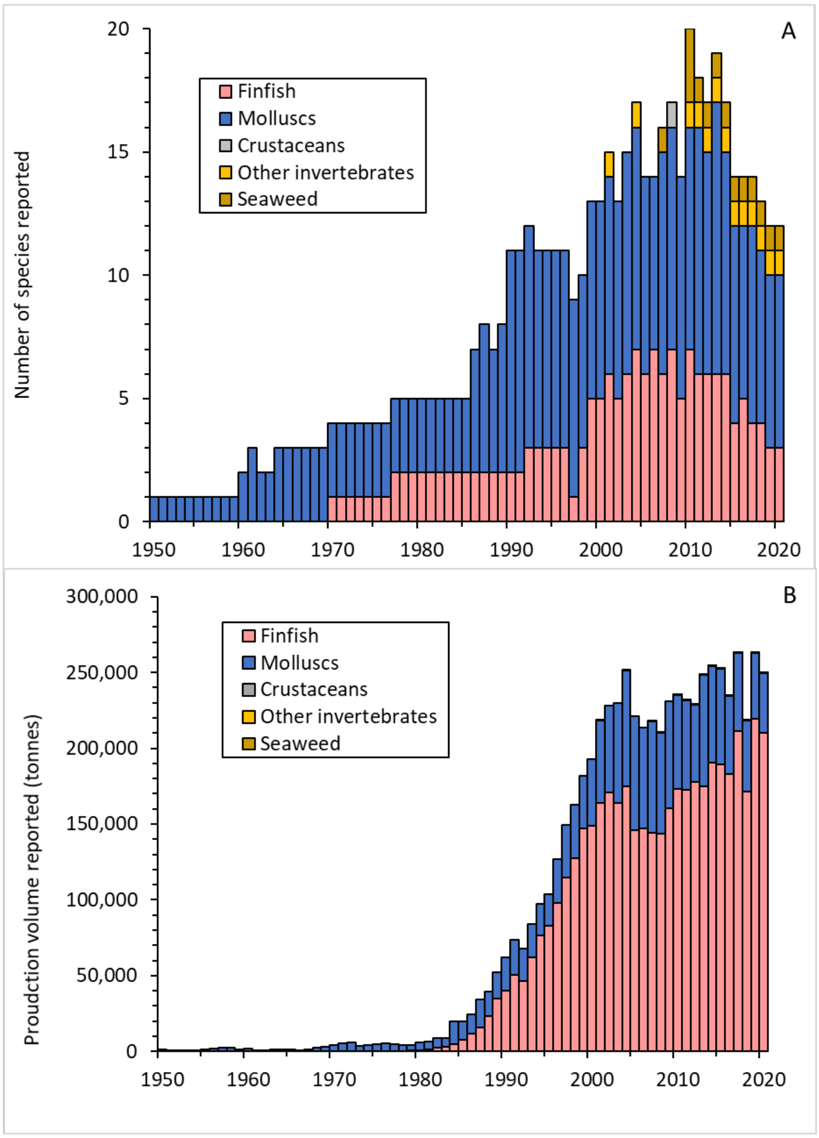

Fig 3.1: Time-series (1950–2020) of aquaculture production tonnage statistics (FAO, 2022) for the ecoregion, differentiated by major taxonomic grouping. A: Annual number of different species reported; B: Annual production tonnage.

3.3 Finfish

3.3.1 On-grown production (finfish)

On-grown production of seawater finfish is dominated by Atlantic salmon (Fig 3.2A). Reported Atlantic salmon production has increased from 244 tonnes in 1970 to a current peak of around 200,000 tpa. The bulk (>90%) of reported production is from Scotland, with the balance from Ireland (Fig 3.2A). In Northern Ireland, a single company established in 2008 produces up to 600 tpa of organically sourced salmon (Glenarm_Organic_Salmon, 2022). Rainbow trout, reported since the late 1970s, is the second ranked and only other finfish species showing growth in production, ca. 4,000 tpa in recent years (Fig 3.2B). The majority of Atlantic salmon and rainbow trout production is from net-pens, with a minor contribution from onshore tanks (Scottish Government, 2021a).

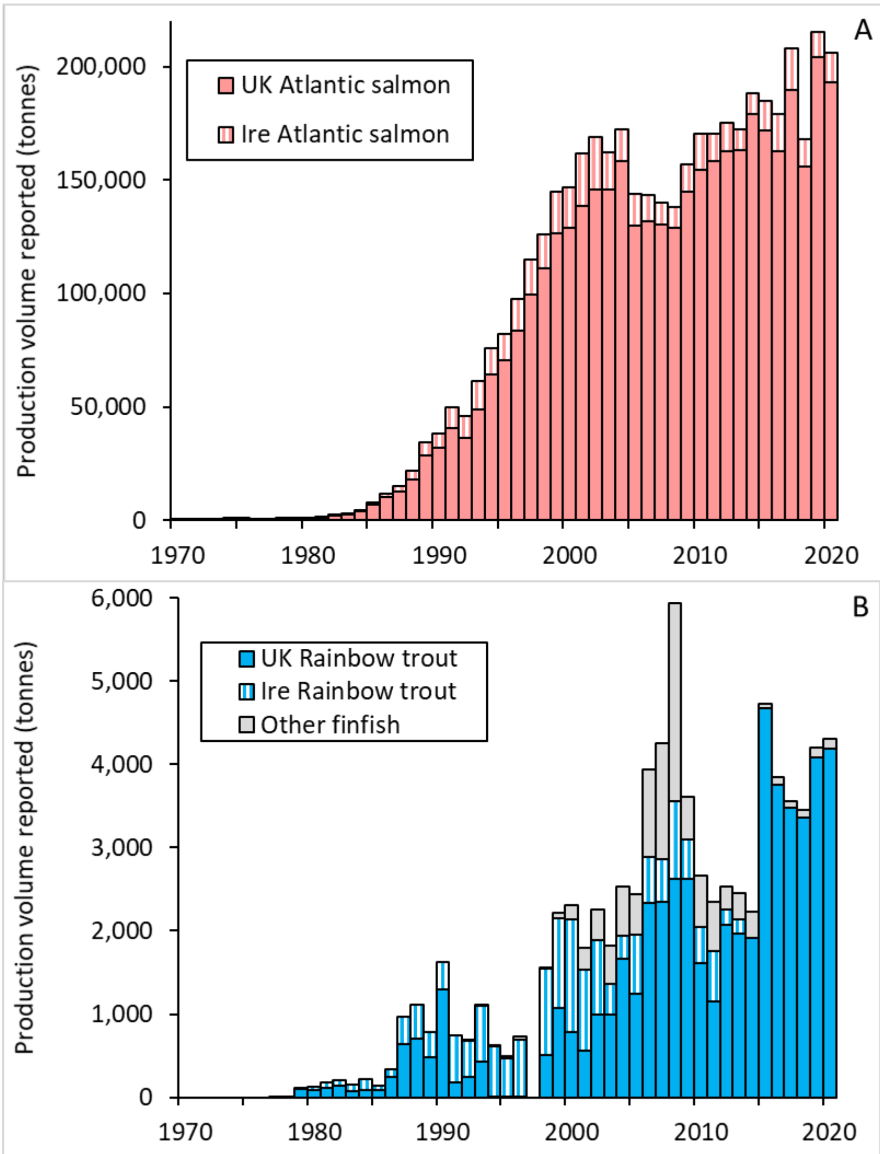

Fig 3.2: Time-series (1970–2020) of finfish aquaculture production tonnage statistics (FAO, 2022). A: Atlantic salmon; B: Rainbow trout and other species (see text for details).

The other finfish species ranked in descending order of total production from (FAO, 2022) are:

- **Atlantic cod** *Gadus morhua*, peak in 2008 of 1,822 tonnes produced in Scotland (Scottish Government, 2021a)
- **Atlantic halibut** *Hippoglossus hippoglossus*, peak in 2005 of 272 tonnes produced in Scotland, although production for years ≥2017 is confidential (Scottish Government, 2021a).
- **European sea bass** *Dicentrarchus labrax* on a large pump-ashore RAS site in north Wales, which reported production of up to 500 tpa between 2008 and 2014 (Ellis et al., 2015).
- **Sea trout** *Salmo trutta*, peak in 2008 of 311 tonnes. N.B.: Reported seawater production may erroneously include freshwater production of "brown" trout (Reese, 2010).
- **Marine fishes nei** (= not elsewhere identified], a statistical category used where the species is uncertain or confidential.
- **Turbot** *Scophthalmus maximus*, peak in 2004 of 258 tonnes. Turbot production has been reported for the UK, Ireland and Channel Islands (FAO, 2022). Turbot are the only marine finfish species farmed in the Channel Islands, with small-scale production (≤ 2.8 tonnes p.a.) being reported since 2008; this appears to be from a single company operating a pump-ashore / recirculation farm (Genuine_Jersey, 2022; GOV.JE, 2022; Syvret and Fitzgerald, 2010).
- **Haddock** (*Melanogrammus aeglefinus)*, with a single report of 4 tonnes in 2006.

Further finfish production is missing from the (FAO, 2022) statistics, likely due to lack of data collection, relatively minor volumes and/or confidentiality, e.g.:

- 1980s production of turbot in Scotland, of around 100 tpa, possibly in association with cooling water from a power station (Person-Le Rujet, 1990).
- barramundi (= giant seaperch, *Lates calcarifer*) in inland RAS in England in the mid-2000s (Anon., 2006)

3.3.2 Hatchery production for ongrowing (finfish)

The on-grown production above is dependent upon production by hatcheries and nurseries producing ova and juveniles. It is notable that the majority of Atlantic salmon and rainbow trout ova laid down are imported/foreign (Scottish Government, 2021a). On the Isle of Man, there is a large commercial rainbow trout hatchery supplying European aquaculture (Troutlodge, 2022) and historically the island hosted a pioneering marine fish research hatchery (Shelbourne, 1963), a commercial turbot hatchery (Ellis and Nash, 1998), and a commercial turbot and halibut hatchery (Baynes et al., 2004).

A relatively recent development is the hatchery production of juvenile lumpfish *Cyclopterus lumpus* and wrasse spp. (*Labridae*) as cleaner fish for biological control of sea-lice in seawater salmonid farming. Production statistics are typically excluded from databases because cleaner fish are not an aquaculture product for consumption (EuroStat, 2018).

Production of cleaner fish occurs in:

- Scotland: Statistics have been reported by tonnage (≥2013) and number (≥2015), the latter better reflecting such hatchery/nursery output (Fig 3.3). In 2020, the reported number of farmed cleaner fish produced in Scotland rose sharply to 15 million.
- England: in a joint venture with a salmon farming company, a Dorset-based company has been producing lumpfish in shore-based RAS since 2013 to supply Scottish salmon farms (Dorset_&_East_Devon_Aquacaulture, 2022). Production is confidential, although suggested to be around 0.95 million p.a. (Dorset_&_East_Devon_Aquacaulture, 2022).
- Wales: In North Wales, RAS sites previously used to grow turbot and European sea bass have switched to lumpfish and ballan wrasse; there is further lumpfish production in

South Wales (Hatchery_International, 2020; MOWI_Scotland, 2021; Swansea_University, n.d.; Three-sixty_Aquaculture, n.d.). Production is confidential due to the limited number of producers.

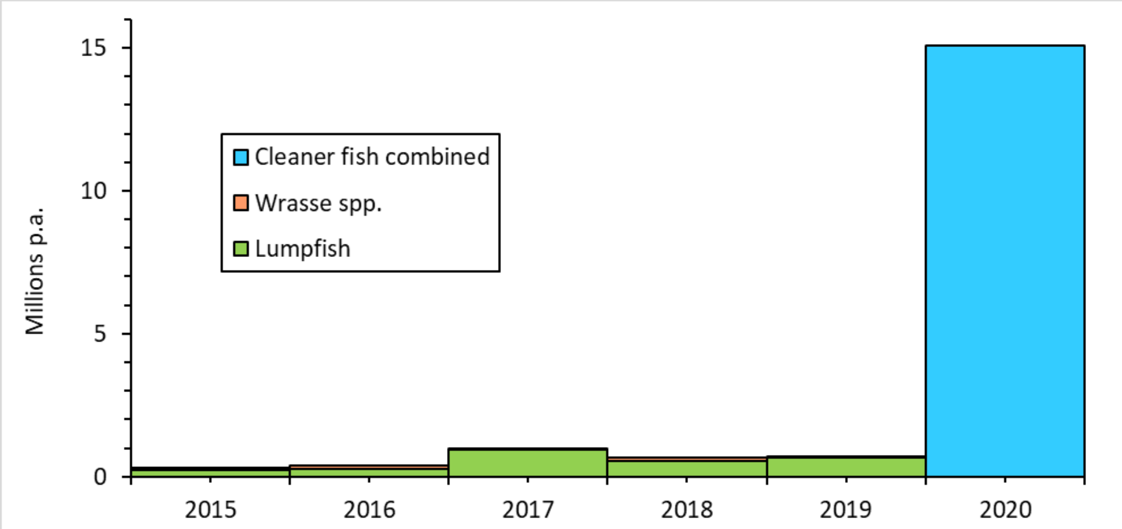

Figure 3.3 Available time-series (2015–2020) of numbers of farmed cleaner fish produced in Scotland. Data from (Scottish Government, 2022, 2021a).

3.3.3 Hatchery production for environmental stocking (finfish)

Anadromous salmonids (Atlantic salmon and sea trout) are produced in hatcheries for environmental stocking. The availability of data varies:

- Ireland: Patchy data for juvenile Atlantic salmon released to the wild are available (EuroStat, 2022)
- Scotland: Stocking does occur (Fishupdate.com, 2014; Hjul, 2019a, 2019b; Stewart et al., 2015), but data are not collected to produce statistics.
- Northern Ireland, England, Wales: Data are collected (Cefas FHI, n.d.; DAERA-NI, n.d.), but some figures published for the UK (EuroStat, 2018) are judged to be erroneous.
- Isle of Man: a hatchery (GOV.IM, 2022) is thought to produce fish for environmental stocking, but data are not published.

The available time-series of production for environmental stocking indicates a marked decline (Figure 3.4), which is likely to be associated with changing policy on stocking (Gray and Charleston, 2011).

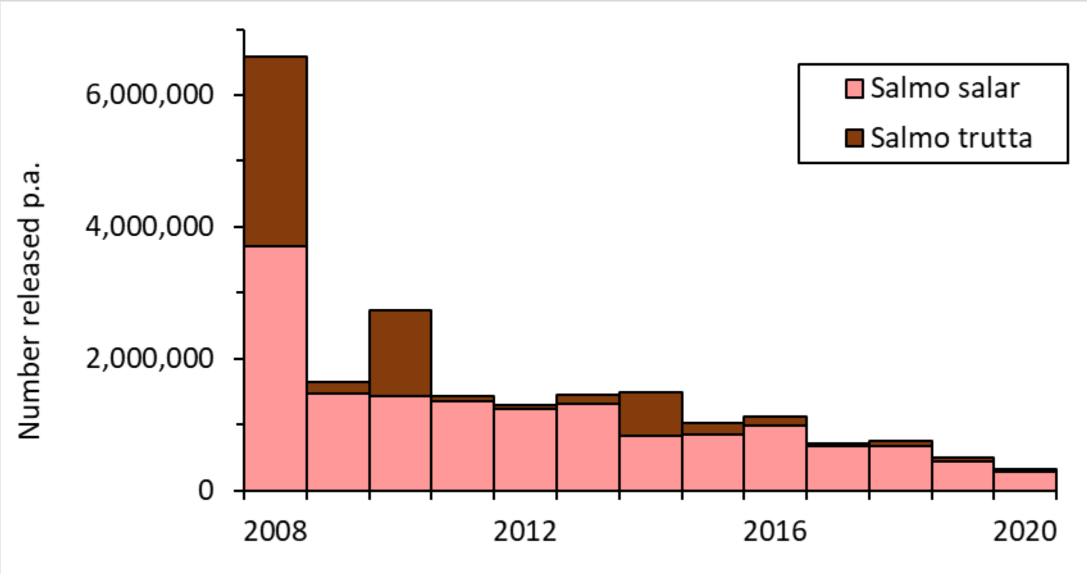

Figure 3.4 Available time-series (2008–2020) of numbers of juvenile anadromous salmonids produced for environmental stocking in Ireland, Northern Ireland, England and Wales. Reconstructed from (Cefas FHI, n.d.; DAERA-NI, n.d.; Ellis et al., 2015; EuroStat, 2022). N.B. Some anomalous UK data in (EuroStat, 2022) excluded, thought due to likely confusion between production of juveniles for stocking and ongrowing.

3.3.4 Wild production input to aquaculture (finfish)

Wild wrasses are caught from coastal waters around Ireland, Scotland and southwest England for deployment as cleaner fish in salmon net-pens for biological control of sea-lice. This use of wild wrasse initiated in the late 1980s/early 1990s (Deady et al., 1995; Treasurer, 1994), then largely stopped when new chemotherapeutants were introduced, but returned in the mid-2010s (Riley et al., 2017). Clear statistics on the input to aquaculture are lacking (Riley et al., 2017). The industry body for Scotland has published figures for 2018 and 2019 for "*the first 20 traps lifted weekly by Scottish fishing boats providing wrasse to the Scottish salmon farming sector*" (Salmon_Scotland, 2021). These data indicate input of >30,000 wild Scottish wrasse in 2019 across five species (rock cook *Centrolabrus exoletus*, goldsinny wrasse *Ctenolabrus rupestris*; cuckoo wrasse *Labrus mixtus*; corkwing wrasse *Symphodus melops*; ballan wrasse *Labrus bergylta*).

The UK reported wild-caught juvenile European eel *Anguilla anguilla* as an input to (European) aquaculture for the years 2013-2018, ranging from 0.64–3.5 tpa (EuroStat, 2022). Fisheries for glass eels occurred on rivers/estuaries in SW England, although it is understood that this practice has ceased with EU-exit, due to the new requirement for CITES permits for international (rather than within EU) trade. This potential aquaculture resource is therefore no longer being exploited. To mitigate the potential impact of glass eel fisheries on wild populations, 60% of catches were required to be used to stock wild habitats (EC, 2007).

3.4 Molluscs

3.4.1 On-grown production (molluscs)

The (FAO, 2022) aquaculture production statistics for the region include eleven mollusc species (groups). The species, ranked in descending order of total production are:

- ***Mytilus spp*** (= blue mussel *Mytilus edulis* + Mediterranean mussel *M. galloprovincialis* + sea mussels nei). Although blue mussel is the main farmed species, this species is mixed on farms with Mediterranean mussel, the non-native *M. trossulus*, and hybrids (Dias et al., 2009; Laing and Spencer, 2006). Production has been reported annually by Ireland since 1950, the UK since 1984, and the Channel Islands since 1999. Production across the region peaked in 2004 at 68,000 tonnes, but has since dropped by 60% (Fig 3.5A).
- **Pacific cupped oyster** (incl. *Cupped oysters* nei): Production has been reported annually by the UK since 1961, Ireland since 1970, and the Channel Islands since 1986. Production of this non-native species is increasing across the region, and is currently around 14,000 tpa with the majority being produced in Ireland (Figure 3.5B).
- **European flat oyster**: Production has been reported annually by Ireland since 1960, the UK since 1987, and the Channel Islands sporadically since 2013. Production of this native species has decreased from a peak of 900 to 250 tpa Fig 3.5C).
- **Common edible cockle** *Cerastoderma edule*: Production reported by the UK varies markedly over time (0–5,000 tpa.; Fig 3.5D). Whether production of this wild-seeded species reported from aquaculture sites/enterprises should be classed as aquaculture is debatable (Burton et al., 2001; Howard, 1996).
- **Japanese carpet shell** (aka Manila clam) *Ruditapes philippinarum:* Production of this non-native species has been reported by Ireland and the UK since 1990. Production has dropped from a peak of 300 to 10 tpa (Figure 3.6E).
- **Great Atlantic scallop** *Pecten maximus*: Production has been reported annually by the UK since 1986, the Channel Islands since 1994, and Ireland between 1995 and 2016. Production has fallen to negligible volumes over the last 20 years from a peak of 120 tpa (Figure 3.5F).
- **Queen scallop** *Aequipecten opercularis:* The UK has reported production since 1986, falling from a peak of 170 tonnes in 1988 to negligible current volumes.
- **Northern quahog** (= Hard clam) *Mercenaria.* The UK has reported intermittent production of this non-native species since 2003.
- **Marine molluscs nei**: Ireland and the UK have reported in this statistical category, likely to record production but maintain confidentiality.
- **Grooved carpet shell** *Ruditapes decussatus*: The UK and Channel Islands have reported intermittent minor production of this native clam.
- **Abalones nei** (+ tuberculate abalone *Haliotis tuberculate*): Ireland and the Channel Islands have reported minor production between 2008–2013.

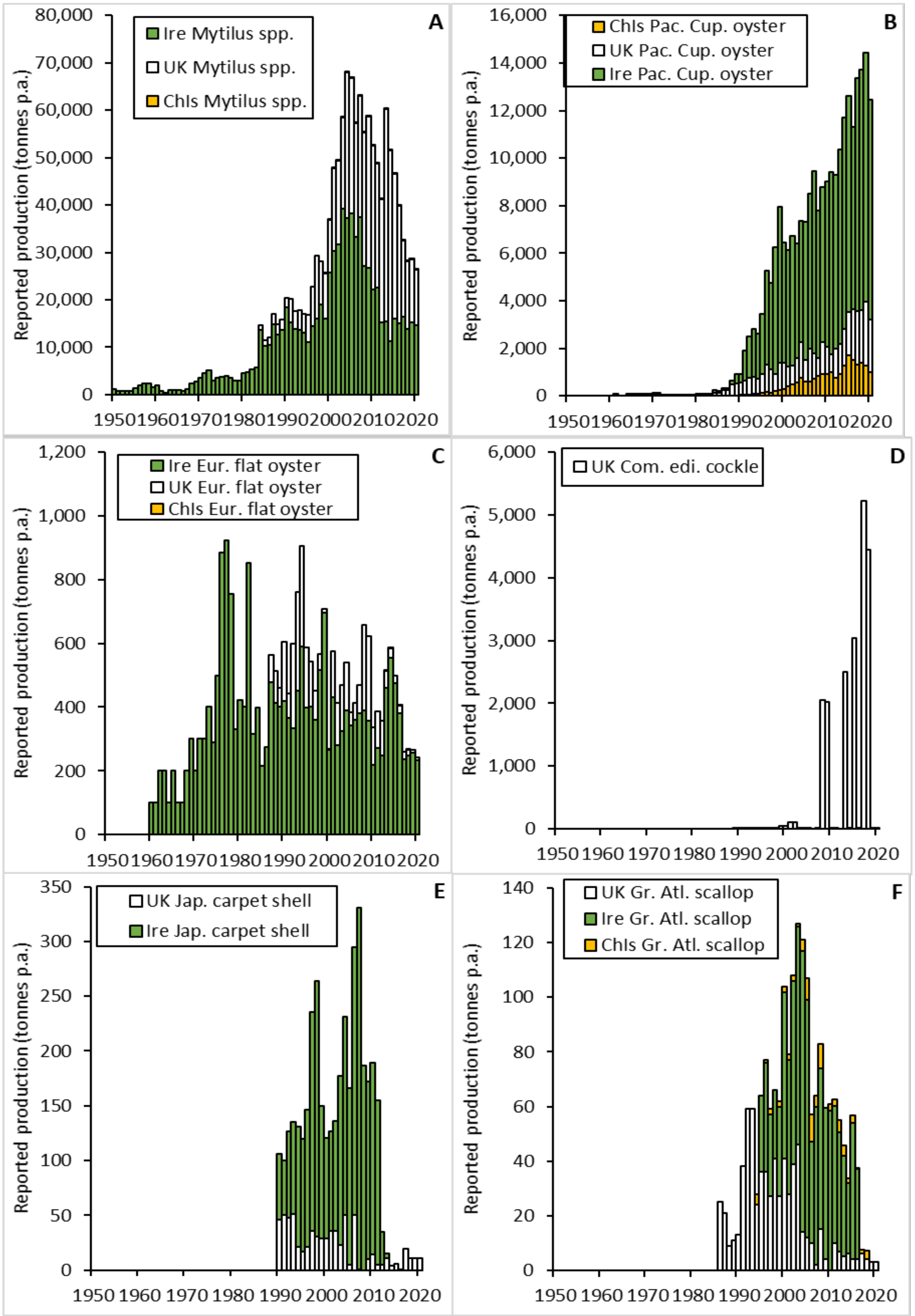

Figure 3.5 Available time-series (1950–2020) of aquaculture production tonnage statistics for mollusc species from Ireland (Ire), the UK and Channel Island (ChIs). Data from (FAO, 2022). A: *Mytilus* spp.; B: Pacific cupped oyster; C: European flat oyster; D: Common edible cockle; E: Japanese carpet shell; F: Great Atlantic scallop.

3.4.2 Hatchery production for ongrowing (molluscs)

Reliable time-series data on hatchery production of molluscs in the region is lacking due to the limited number of enterprises. There is a notable bivalve hatchery (Guernsey_Sea_Farms, n.d.) that supplies diploid and triploid Pacific cupped oyster seed to the UK aquaculture industry, as well as oyster larvae, copepods and microalgae for eco-toxicity testing (Adamson et al., 2018; Guernsey_Sea_Farms, n.d.). There is also commercial shellfish hatchery production of oyster spat in England (Adamson et al., 2018). Historically there has been a lack of bivalve hatchery production in Scotland, although "nursery" production is sold for on-growing (Scottish Government, 2022). However, a commercial European flat oyster hatchery recently started in Orkney, and an experimental mussel hatchery was piloted in Shetland (Orkney_Shellfish_Hatchery, 2021; UHI, n.d.).

3.4.3 Hatchery production for environmental stocking (molluscs)

There is current activity in hatchery production of European flat oyster for environmental stocking in Ireland, the UK and Channel Islands (Native oyster network: UK & Ireland, n.d.), although statistics are not available.

3.4.4 Wild production input to aquaculture (molluscs)

Input of wild mollusc seed to aquaculture has been reported by Ireland and the UK (EuroStat, 2022) for:

- ***Mytilus* spp**. There has been a decline in the input of wild seed over the period for which data are available (Figure 3.6). This decline is contemporaneous with the decline in harvested production.
- **Pacific cupped oyster:** The UK reported input of 3 tonnes in 2009 and 44.91 tonnes in 2014.
- **European flat oyster**: Ireland has reported inputs of around 375 tonnes, but just in 2008–2009. The UK reported input of 0.04 tonnes in 2009.

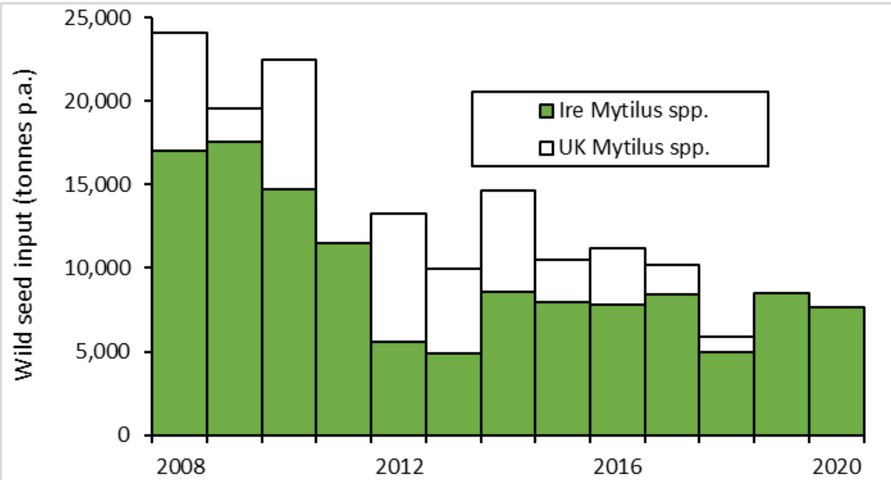

Figure 3.6 Available time-series (2008–2020) of wild input of *Mytilus* spp. seed to aquaculture. Statistics from (EuroStat, 2022), but note lacking for UK after 2018.

3.5 Crustaceans

3.5.1 On-grown production (crustaceans)

Reported production of seawater crustaceans is limited to small-scale production of tropical whiteleg shrimp (*Penaeus vannamei*) in inland heated RAS: the UK reported 2 tonnes in 2008 (FAO, 2022). Research into ongrowing European lobster for the table has been undertaken (National_Lobster_Hatchery, 2016; The_Fish_Site, 2008), but no such production has been reported to the FAO.

3.5.2 Hatchery production for ongrowing and environmental stocking (crustaceans)

There are hatcheries producing juvenile European lobster (*Homarus gammarus*) for release in stock enhancement schemes in Scotland (Firth_of_Forth_Lobster_Hatchery, 2022; Orkney_Shellfish_Hatchery, 2021), England (National_Lobster_Hatchery, 2020; Northumberland_Seafood, n.d.; Whitby_Lobster_Hatchery, 2020) and Wales (Anglesey_Sea_Zoo, n.d.). Published statistics are limited to England which indicate an increasing trend (Figure 3.7).

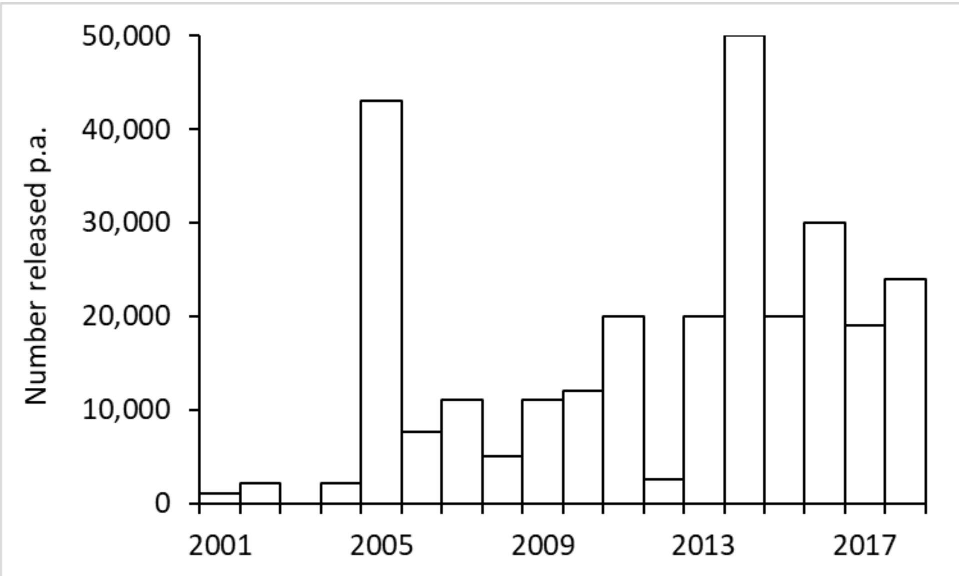

Figure 3.7 Available time-series (2001–2018) of production of juvenile European lobster from English hatcheries for release in stock enhancement schemes. Data from (Ellis et al., 2015; EuroStat, 2022).

There has been also been research in Wales into hatchery production of Norway lobster *Nephrops norvegicus* and common spiny lobster *Palinurus elephas* for stock enhancement (Anglesey_Sea_Zoo, n.d.; Powell and Eriksson, 2013).

3.6 Other marine invertebrates

Reported production of other marine invertebrates in the region is limited to:

- **Stony sea urchin** *Paracentrotus lividus*: Ireland reported intermittent production of 0.5–5 tpa between 2001–2013 (FAO, 2022).

- **Aquatic invertebrates nei:** Ireland reported production of 4–57 tpa between 2014–2020 (FAO, 2022).

In addition, there have been two commercial farms producing marine worms for sale as angling bait and feed for marine finfish and shrimp broodstock: one in England produced ca. 50 tpa of king ragworm (*Alitta virens*) in the 1980s–2000s (Vaughan-Adams, 2003); one in Wales has produced ≤25 tpa of king ragworm and harbour ragworm (*Hediste diversicolor*) since 1999 (Dragon_Baits, 2022). Aquaculture production of marine worms provides an alternative to traditional fisheries for wild worms which are associated with environmental pressures (Watson et al., 2017).

3.7 Seawater plants

Statistics on farmed seaweed production are only available for Ireland, with production being reported since 2007 across four species: dabberlocks *Alaria esculenta*, brown seaweeds *Phaeophyceae*, dulse *Palmaria palmata* and Tangle *Laminaria digitata.* Production peaked at 100 tonnes in 2014 (Figure 3.8).

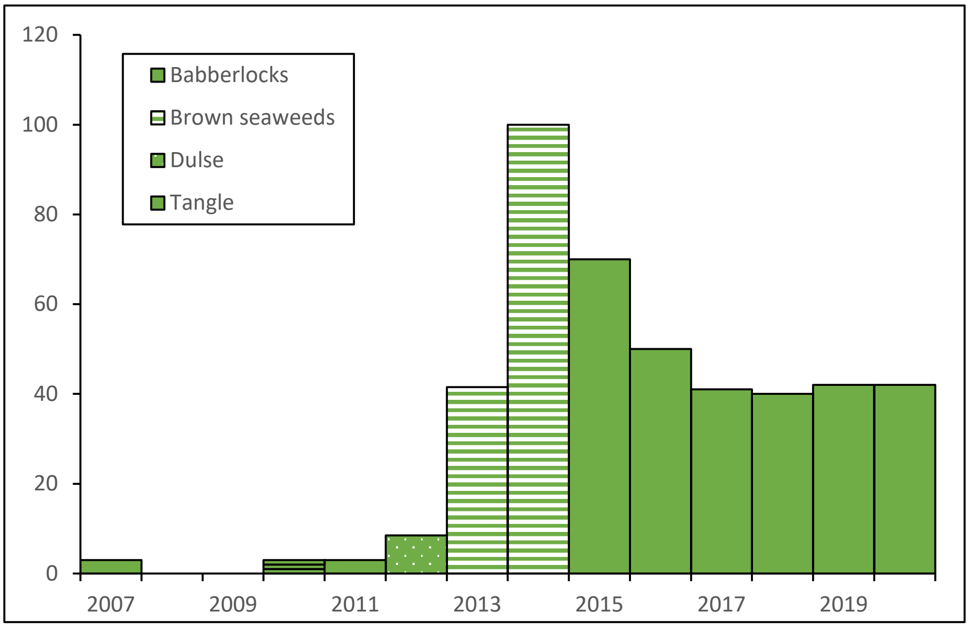

Figure 3.8 Available time-series (2007–2020) of production of farmed seaweed in Ireland. Data from (FAO, 2022).

Although production statistics are not available, seaweed farming does occur elsewhere in the region:

- In Northern Ireland there is a commercial seaweed farm growing sea belt (sugar kelp, *Saccharina latissimi*), tangle (kombu) and dabberlocks (wakame) (Islander_Rathlin_Kelp, n.d.). There is also active research into seaweed hatchery and ongrowing production (Queen's_University_of_Belfast, n.d.).
- In Scotland there is governmental interest in encouraging seaweed farming (Scottish Government, 2017), experimental farms, research and hatchery support (SAMS, n.d.), and a developing industry, e.g. (Seaweed_Farming_Scotland, n.d.).
- In England, a number of commercial seaweed farms have recently started, e.g. (Dorset_&_East_Devon_Aquaculture, 2022; Seagrown, 2022; The_Cornish_Seaweed_Company_Ltd, 2017).

- In Wales, there is interest in developing seaweed farming e.g. (Car-y-Mor, 2022; GreenSeas_Resources, n.d.; Seaweed_Forum_Wales, 2017).
- On the Isle of Man, a commercial seaweed farm operated in the early 1990s (Butler, 1992; Kenicer et al., 2000).

In relation to production of other marine plants:

- A research project in Wales examined the integrated hydroponic production of marsh samphire (*Salicornia europaea*) in the wastewater from a pump-ashore marine finfish farm (Webb et al., 2009).
- Seagrass (*Zostera spp.*) culture for environmental stocking has started recently in England and Wales (Gamble et al., 2021; National_Marine_Aquarium, 2022), but no statistics are available.

4 Policy and Legal Foundation

Aquaculture policy within the UK is a devolved matter. Each of the separate administrations of Wales, England, Northern Ireland and Scotland is responsible for its collective oversight (DEFRA 2015).

In the Republic of Ireland, aquaculture policy and licencing is overseen by the Minister of Agriculture, Food and the Marine. In addition to regulations governing licencing and management of aquaculture operations, the broad policy relating to sustainable aquaculture development and regulation is one of the main objectives of the EU common fisheries policy (and successors). At an EU level, aquaculture production is also recognized through the European Green Deal and the Farm to Fork Strategy as a source of "low carbon" protein for food and feed. In Ireland, aquaculture development is subject to licencing and monitoring procedures and it must comply with strict requirements under both EU and national legislation to ensure it respects human and animal health and the environment. This is most important in terms of environmental sustainability relating to the assessment, monitoring and limitation of the environmental impact of aquaculture activities. This is affected by the implementation of the National Strategic Plan for Sustainable Aquaculture Development. This is a multiyear plan to ensure sustainable development of the industry while complying fully with environmental legislative requirements.

4.1 Licensing

Aquaculture production within the Celtic Seas ecoregion requires licenses.

4.1.1 Ireland

In the Republic of Ireland, it is illegal to engage in aquaculture without an Aquaculture Licence. The Minister (Department) for Agriculture, Food and the Marine is responsible for licencing aquaculture. Within that Department (DAFM) the Aquaculture and Foreshore Management Division, on behalf of the Minister, oversees aquaculture licensing under the Fisheries (Amendment) Act, 1997 (as amended). Within the Act, Aquaculture is defined as the culture or farming of fish, aquatic invertebrates, aquatic plants or any aquatic form of food suitable for the nutrition of fish.

In addition, applications for coastal aquaculture operations also require a Foreshore Licence from the Minister for Agriculture, Food and the Marine under the Foreshore Act 1933 (as amended). This Act specifically relates to the location of structures on the foreshore.

Licencing of aquaculture operations must engage in public consultation and consultation with such bodies, including statutory bodies, as may be prescribed for that purpose. In Ireland, such Statutory bodies include, the Marine Institute, the Irish Sea Fisheries Board (Bord Iascaigh Mhara-BIM), National Parks and Wildlife Service (NPWS) of the Department (Minister) Housing, Local Government and Heritage, Údaras na Gaeltachta, Local Authorities, Failte Ireland, Inland Fisheries Ireland, Commissioners of Irish Lights, An Taisce (The National Trust for Ireland), Harbour Authorities and Department of Transport. Observations provided as part of the aquaculture licencing consultation are communicated to DAFM which are then considered in the decision-making process.

Furthermore, during deliberations of aquaculture licence applications, DAFM must consider wider Environmental legislation including provisions under, among others, the EU Birds and Habitats Directives as well as the Environmental Impact Assessment Directive. It is important to note that most applications for marine finfish licences, defined as intensive fish farming operations[6], must be accompanied by an Environmental Impact Assessment Report (EIAR). Shellfish culture and other (e.g. seaweed) operations which are defined as extensive fish farming operations are not typically subject to EIA. For land-based developments, e.g. hatcheries, the applicant must have obtained planning permission (and relevant discharge license, if necessary) from the local authority before applying for an aquaculture licence.

Under EU habitats and Birds regulations[7] it is required that the licencing body considers the interactions between the proposed activity and the integrity of Natura 2000 sites. Under Article 6(3) of the Habitats Directive any plan or project likely to significantly affect the integrity of a Natura 2000 site must be subject to an Appropriate Assessment (AA). AA focuses on the likely significant effects of a plan or project on a Natura 2000 site and considers the implications for the site in view of its' conservation objectives. Every Natura 2000 site has Conservation Objectives which are set out by the National Parks and Wildlife Service (NPWS), a competent authority for the management of Natura 2000 sites in Ireland. The AA process also must consider any plan or proposal in-combination with other activities that have the potential to significantly affect the integrity of the Natura 2000 site. DAFM as the aquaculture licensing authority for aquaculture activities is also the competent authority responsible for undertaking AA of aquaculture licence applications.

Additionally, consideration must be given to the status of species proposed for culture under the Council Regulation (EC) No 708/2007 which requires that the translocation/introduction of Alien and Locally Absent Species to be authorized by DAFM (subject to risk analysis), and to be recorded in a publicly available register. It allows exceptions for specific cases such as closed recirculation systems, where the risks of interactions with the external environment are minimal. It also recognizes that some alien species have commonly been used in aquaculture for a long time in certain parts of the EU – for example, the Pacific Oyster. These species, listed in Annex IV to the Regulation, are exempt from most provisions of the Regulation.

Aquaculture and Foreshore Licence templates have been developed and area available on the DAFM website (https://www.gov.ie/en/publication/fcd20-aquaculture-foreshore-management/#aquaculture-licensing).

The applicant must acquire a Fish Health Authorisation from the Marine Institute which is the Competent Authority, under the European Communities (Health of Aquaculture Animals and Products) Regulations 2008 (S.I. No. 261 of 2008), European Communities (Health of Aquaculture Animals and Products (Amendment) Regulations 2010 (S.I. No. 398 of 2010) and European Communities Health of Aquaculture Animals and Products (Amendment) Regulations 2011 (S.I. No. 430 of 2011). This legislation governs the movement of aquaculture stock between and within countries.

It is noted that any decision taken by the Minister can be appealed (by any person or body) to the Aquaculture Licence Appeals Board (ALAB)[8]. ALAB is an independent body, establish under statute (Fisheries (Amendment) Act, 1997), which will consider the appeal and has the authority to confirm, refuse or vary a decision made by the Minister or issue licences itself under its own authority.

6 Aquaculture (Licence Application) (Amendment) Regulations 2018 - S.I. No. 240 of 2018

7 European Communities (Birds and Natural Habitats) Regulations 2011- Sin No. 477 of 2011

8 www.alab.ie

4.1.2 Northern Ireland

Within the Northern Ireland, the Marine and Fisheries Division of the Department of Agriculture, Environment and Rural Affairs (DAERA)[9], is responsible for the granting of aquaculture licences under the Fisheries Act (Northern Ireland) 1966, as amended. There are three types of aquaculture license granted under the Fisheries Act (Northern Ireland) 1966, a fish culture licence, a shellfishery licence and a marine fishery licence.

A fish culture licence is compulsory for all fish and shellfish farms. It is an offence to operate a fish farm without a fish culture licence. A shellfishery licence is an optional additional licence for shellfish farmers and gives the licence holder the exclusive right to cultivate a particular shellfish species within a specified area. It also gives the licence holder legislative protection of their operations. A marine fishery licence is an optional additional licence for marine fish farms. Similar to a shellfishery licence, a marine fishery licence gives the licence holder the exclusive right to cultivate a particular marine fish species within a specified area. It also gives the licence holder legislative protection of their operations.

When applying for a fish culture Licence and a Shellfish fishery Licence for shellfish farming in the sea or tidal waters (FF2 Application) the applicant must provide;

- a chart indicating the exact coordinates and size of the site,
- confirmation of ownership or lease of the site from the Crown Estate Commissioners or other owner of the seabed of Foreshore,
- written confirmation from the Maritime and Coastguard Agency that the proposed development will not create a navigational hazard and
- a business plan in support of the proposed operation.

When applying for a Fish culture Licence and a Marine Fish fishery Licence for Finfish farming in the sea (FF3 Application) the applicant must provide;

- an ordnance survey map indicating the exact location and size of the site,
- confirmation of ownership or lease of the site
- where appropriate planning permission,
- a copy of the consent to discharge effluent granted by the DAERA, Water Management Unit, or written confirmation that such consent has been applied for under the Water Order (Northern Ireland) 1999.
- a business plan in support of the proposed operation.

Application forms and a guide to the fish culture licensing process are available on the DAERA website (https://www.daera-ni.gov.uk/publications/guide-fish-culture-licensing-process).

Any application for a fish culture licence for a marine fish farm (excluding shellfish) where any part of the proposed development is within a sensitive area, is designed to hold a biomass of 100 tonnes or greater, or will extend to 0.1 Hectares or more, is also subject to the provisions of The Marine Works (Environmental Impact Assessment) Regulations 2007 and The Marine Works (Environmental Impact Assessment) (Amendment) Regulations 2017.

All applications for fish culture licences within Northern Irish jurisdiction that are within or adjacent to a Marine Protected Area (MPA) are subject to assessment under the Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995, known as a Habitat Regulations Assessment (HRA). Therefore, before a new aquaculture site within or adjacent to a MPA can be

[9] https://www.daera-ni.gov.uk/articles/aquaculture-and-licensing-aquaculture-establishments

licensed it must first be demonstrated (by means of the HRA report) that the proposed new site will not impact upon the conservation objectives of the designated site in question.

4.1.3 Transboundary areas

There are two transboundary Sea Loughs which border Northern Ireland and the Republic of Ireland (Carlingford Lough, in the Southeast of the Island of Ireland and Lough Foyle, in the Northwest). Whilst the position of the land border is known, the position of where maritime boundaries *could* lie are much more complex and, in relation to Carlingford Lough and Lough Foyle, have never been formally agreed. Because of the central geographical position of the navigation channel in the inner part of Carlingford Lough, this is used by regulatory authorities as a *de facto* border when carrying out their responsibilities (Poppleton *et al* 2021)[10].

Generally maritime delimitation is governed by the United Nations Convention on the Law of the Sea (UNCLOS)[11]. Article 10 of this Convention deals with bays, in this instance the Loughs, but only those that belong to a single State, meaning Carlingford Lough and Lough Foyle fall outside its scope.

In a move to promote transboundary management of Carlingford Lough and Lough Foyle the Loughs Agency (an agency of the Foyle, Carlingford and Irish Lights Commission (FCILC)) was set up as one of the North-South Implementation Bodies under the 1998 Agreement between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of Ireland (also known as the Belfast Agreement or the Good Friday Agreement, GFA)[12].

Legally, the Agency's responsibilities are to promote the development of the Loughs for commercial and recreational purposes in respect of marine, fishery and aquaculture matters; to manage, conserve, protect, improve and develop the inland fisheries of the Foyle and Carlingford Areas; to develop and licence aquaculture; and to develop marine tourism.

The Foyle and Carlingford Fisheries (Northern Ireland) Order 2007 and the Foyle and Carlingford Fisheries Act, 2007 (ROI) provided for a new regulatory system for aquaculture in the Foyle and Carlingford areas. To date those powers have not been enacted, in the form of a management agreement, so as to allow the Loughs Agency to manage, on behalf of both Governments, marine aquaculture in Lough Foyle. Evidence to the House of Commons Northern Ireland Affairs Committee, published in 2018, says that this situation has led to the number of unlicensed oyster trestles in Lough Foyle growing from around 2,500 in 2010–11 to approximately 50,000 in 2016. The recommendation from that Committee was that the UK's Foreign and Commonwealth Office conclude a management agreement with the Irish Government, within the next 12 months, to allow the Lough's Agency to fully implement the 2007 Foyle and Carlingford Fisheries Order.

At time of print, the powers to undertake all these functions have not yet been transferred to the Loughs Agency. They currently have no regulatory authority for aquaculture activities within the marine waters of Carlingford Lough or Lough Foyle.

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10 Poppleton, V., Boyd, A., O'Hagan, A.M., and Wilson. R. 2021. Report providing practical guidance on transboundary working between Northern Ireland and the Republic of Ireland: Focusing on aquaculture in Carlingford Lough. Deliverable 2.1 of the SIMAtlantic project (EASME/EMFF/2018/1.2.1.5/SI2.806423). 57 pp. https://www.simatlantic.eu/wp-content/uploads/2022/05/D2.1-Carlingford-Lough-Guidance.pdf

11 https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

12 https://www.gov.uk/government/publications/the-belfast-agreement).

4.1.4 Scotland

From April 2007 all new fish and shellfish aquaculture development within Scotland requires planning permission under the Town and Country Planning Act from the relevant Planning Authority. Marine aquaculture operators within Scotland must also apply for a lease from The Crown Estate and pay rent to install and operate the farm on the seabed. Before any equipment can be installed a marine licence is required from the Marine Scotland Licensing Operations Team.

Within Scotland all aquaculture farms must meet strict guidelines to ensure that environmental impacts are fully assessed and ultimately managed in a safe manner. Finfish farms are listed under Schedule 2 of the 2017 Environmental Impact Assessment (EIA) Regulations[13]. This means that they will require an EIA if they are likely to have a significant effect on the environment. The majority of finfish applications will be screened to determine whether or not an EIA is required. If the Local Authority decides that an EIA is required then this report must be submitted at the same time as the planning application. Shellfish farms in Scotland are not subject to EIA however Local Authorities will still consider the potential environmental impacts of these applications before a licence is granted.

Operators of fish farms are also required to apply for a Controlled Activities Regulations (CAR) Licence which sets site-specific limits on the amount of fish held and the amount of medicines and chemicals that can be used at each site. These standards area enforced by the Scottish Environmental Protection Agency (SEPA).

4.1.5 England

The key aquaculture consenting framework in England comprises the following (including the main regulators) (DEFRA, 2015)[14]:

- Planning permission from the local authority
- Authorization by the Fish Health Inspectorate under Aquatic Animal Health (England and Wales) regulations 2009 (https://www.gov.uk/fish-and-shellfish-farm- authorisation-and-registration); and the Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011 if applicable.
- Land use consent from The Crown Estate or other land owner (http://www.thecrownestate.co.uk)
- Abstraction licences http://www/environement-agency.uk
- Local authority permissions (food hygiene and safety);
- Marine Development/Construction license from the Marine Management Organisation (http://www.marinemanagement.org.uk/)
- Discharge consents (http://www.environment-agency.gov.uk/)
- Those operating in the aquaculture sector must also abide by the Gangmasters (Licensing) Act 2004. (http://gla.defra.gov.uk/)
- Activities also need to comply with environmental regulations if in an area of statutory protection (such as a Site of Special Scientific Interest (SSSI), European Marine Site, or Marine Conservation Zone) and will need to be consented and/or assessed accordingly by the Competent Authority in question:

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13 https://www.legislation.gov.uk/ssi/2017/102/contents/made

14 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/480928/sustainable-aquaculture-manp-uk-2015.pdf

- Natural England. (http://www.naturalengland.org.uk/)
- The local Inshore Fisheries and Conservation Authority (IFCA) (http://www.association-ifca.org.uk)

The Shellfish Act (1967) made provision for 'the establishment or improvement, and for the maintenance and regulation, of a fishery for shellfish.'[15] This Act makes provisions for members of the public or agencies, including local authority bodies, to apply for 'several' or 'regulating' orders, which allow the management of private and natural fisheries. 'Several Orders allow legal ownership of certain named shellfish species within a private shellfishery. Regulating Orders allow management rights to designated natural shellfisheries.'[16].

The online Aquaculture Regulatory Toolbox for England outlines the complete Licensing process for aquaculture operations within England[17].

4.1.6 Wales

Regulations for new aquaculture licences in Wales are dependent on the nature of the farm. Bottom grown mussel sites, which are the most common form of aquaculture within Wales, are authorized via Orders under the Sea Fisheries (Shellfish) Act 1967. A number of possible consents and licences are also required before an aquaculture farm can operate, some of which are listed below (DEFRA, 2015):

The key aquaculture consenting framework in Wales comprises:

- An Order under the Sea Fisheries (Shellfish) Act 1967 (granted by the Welsh Ministers)
- Planning permission from the local authority
- Consent for discharges from a fish farm, or a Marine License for discharge from a boat http://naturalresourceswales.gov.uk
- Abstraction licences http://naturalresourceswales.gov.uk
- License for collecting mussel seed (granted by the Welsh Government)
- Marine Licence for navigational risk (replacing the previous consenting regime under the Coast Protection Act 1949) http://naturalresourceswales.gov.uk
- Marine Licence for construction on the seabed http://naturalresourceswales.gov.uk
- Authorization by the Fish Health Inspectorate under Aquatic Animal Health (England and Wales) regulations 2009 (https://www.gov.uk/fish-and-shellfish-farm- authorisation-and-registration)
- A lease from the Crown Estate or other landowner. (http://www.thecrownestate.co.uk)

It should be noted however that that not all of the consents and licences listed above will apply in every case as the consents required are location and development dependent.

The online Aquaculture Regulatory Toolbox for Wales outlines the complete Licensing process for aquaculture operations within Wales[18].

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[15] Sea Fisheries (Shellfish) Act 1967, https://www.legislation.gov.uk/ukpga/1967/83

[16] Shellfisheries: Several Orders and Regulating Orders, gov.uk, 2013, https://www.gov.uk/guidance/shellfisheries-several-orders-and-regulating-orders

[17] https://www.seafish.org/trade-and-regulation/regulation-in-aquaculture/aquaculture-regulatory-toolbox-for-england/

[18] https://businesswales.gov.wales/marineandfisheries/funding-and-business-development/aquaculture-regulatory-toolbox-wales

Country	Marine finfish	Shellfish (mussels and oysters)	Algae	Other species
Ireland[19]	68	877	14	53
Northern Ireland[20]	2	53	2	
Scotland				
England				
Wales				

[19] AQUAMIS aquaculture licencing viewer.

[20] https://gis.daera-ni.gov.uk/arcgis/apps/webappviewer/index.html?id=e44a8e27333241bfa2faf4a387fd99d7

5 Management Frameworks

Following licencing operators in all jurisdiction are subject to a number of licence conditions that may have been included to mitigate any potential environmental effects. In many cases these may be site or licence specific. However, there may be any number of additional management frameworks in operation that are designed to manage human activities and in specific instances, aquaculture operations. Many of these programmes have a statutory basis, which are underpinned by European or National law. They may fall into a number of broad subject areas and are heavily driven by legislative drivers. They include, the risks posed by disease causing organisms on (and by) aquaculture species and how they are contained or managed. In addition, the output from aquaculture must be safe for consumption by humans. Finally, the impact of aquaculture practices on other species and the environment should be minimised and managed.

The following sections are chosen specifically because they implement post-licencing and therefore, form the basis of management frameworks used in the regulation and oversight of aquaculture activities in the Celtic Seas ecoregion.

5.1 Aquaculture Health Regulations

5.1.1 Ireland

In addition to the aforementioned fish health authorization there is a wide range of national and European legislation governing regulation of fish and shellfish in aquaculture operations.

As outlined above, animal health legislation governing the management of fish health on shellfish and finfish farms is wide ranging and derives primarily from EU legislation. The primary legislation governing the monitoring and management of fish health in Irish aquaculture is Regulation (EU) 2016/429 which puts into effect a monitoring programme to test for diseases listed under the Directive 2006/88/EC and other aquatic diseases of national importance. To this end a number of notifiable diseases are routinely monitoring for in both finfish and shellfish. These diseases are categorised according to risk and nature of response. In 2021, with one exception, Bonamiosis in oysters, Ireland has been declared disease free for all listed finfish and shellfish diseases[21]. Bonamiosis is caused by the protistan parasite, *Bonamia ostrea* and is considered lethal in native oysters, *Ostrea edulis*. There are a number of bays classed as disease-free status in Ireland. Management consists of the restriction of movement of oyster stock and potential vector species between bays. Potential vectors are numerous and mostly consist of other bivalve molluscs.

5.1.2 Northern Ireland

Within Northern Ireland Regulation (EU) 2019/429, known as the Animal Health Law, came into force on the 21st of April 2021. This replaced Council Directive 2006/88/EC in respect of aquatic health. This Regulation outlines parameters for the prevention and control of animal diseases which are transmissible to humans or other animals. This Regulation covers the following areas;

- Disease notification, reporting, surveillance, eradication programmes and disease freedom.

[21] https://www.fishhealth.ie/fhu/sites/default/files/FHU_Files/AquaticDiseaseGuide_09-05-2022.pdf

- Disease awareness, preparedness and control.
- Registration, approval, traceability and movements.
- Movements into the EU.

Regulation (EU) 20016/429 (The Animal Health Law) also requires operators of all Aquaculture Establishments to be registered or approved with the Competent Authority (DAERA) before they commence activities. A biosecurity plan must be submitted with all applications for approval.

DAERA is responsible for the enforcement of the aquatic animal health regime in Northern Ireland. The DAERA Fish Health Inspectorate (FHI) undertake routine inspections and sampling programmes of active aquaculture establishments. DAERA FHI also inspect live fish and shellfish destined for import into and export from Northern Ireland, and issue movement documentation.

5.1.3 Scotland

All marine fish farms within Scotland are authorized by Marine Scotland (MS) under the Aquatic Animal Health (Scotland) Regulations 2009[22]. The Fish Health Inspectorate in MS undertakes assessments for disease control, sea lice management and containment measures[23].

5.1.4 England and Wales

The Aquatic Animal Health and Alien Species in Aquaculture (England and Wales) (Amendment) (EU Exit) Regulations 2018[24] were introduced with the aim of ensuring that legislation within England and Wales regarding aquatic animal health and alien and locally absent species in aquaculture, continue to be operable following the UKs Exit from the EU. It is the responsibility of the Fish Health Inspectorate (based in the Centre for Environment, Fisheries and Aquaculture Science (Cefas)), who report to DEFRA, to prevent the introduction and spread of serious diseases in fish, shellfish and crustacea. This is achieved through:

- managing programmes that monitor the health of fish, shellfish and crustacea
- taking steps to treat and reduce the spread of diseases
- assessing the outbreak, spread and impact of diseases
- investigating unexplained deaths in fish and shellfish
- advising on ways to reduce the risk of spreading infectious diseases[25]

5.2 Monitoring and Management

5.2.1 Ireland

Ensuring aquaculture products are safe for consumption and in particular are free from contamination are covered primarily by EU Regulation - REGULATION (EC) No 1069/2009 primarily covering veterinary medicines, also the EU Residues Directive (96/23) and Shellfish Waters Directive 2006/113/EC focusing on the likely risk of contaminants (i.e. trace metals in

[22] https://www.legislation.gov.uk/ssi/2009/85/contents/made

[23] https://www.gov.scot/policies/fish-health-inspectorate/

[24] https://www.legislation.gov.uk/uksi/2019/452/contents/made

[25] https://www.gov.uk/government/groups/fish-health-inspectorate

shellfish flesh and seawater as well as a wide range of organic compounds) to aquaculture products and the wider environment.

In addition to the risks posed by contaminants on aquaculture products, there are naturally derived hazards in the form of biotoxins that may also greatly impact on human health. On foot of this, there is an extensive biotoxin monitoring programme carried out in Ireland. Regulation EC No 853/2004 governs the total amount of marine biotoxins that may be present in shellfish for the protection of consumers. To this end, shellfish samples from all shellfish production areas are submitted on a weekly basis and analysed for a range of toxins that may cause, Amnesic Shellfish Poisoning, Paralytic Shellfish Poisoning among others.

In recent years and on foot of licencing decisions, monitoring programmes have been implemented in Ireland to ensure that mitigation measures outlined during licencing are considered effective. To this end, monitoring of shorebird distribution in the vicinity of aquaculture operations (typically intertidal shellfish culture) is carried out. The population status and site use of the birds (particularly in relation to interactions with structure and response to disturbance) is monitored at a number of sites during the sensitive overwintering period to ensure population status is stable. In addition, bird monitoring has been used to confirm status of individual species in advance of taking licencing decisions.

Finfish operations are subject to a number of statutory monitoring programmes with the focus of protecting the wider environment and managing the impact of finfish operations. The protocols used[26] are specific to monitoring water quality, benthos, sea lice and ensuring that each site has in-place, appropriate fallowing between production to ensure appropriate break in disease or parasite cycles.

Under the benthos monitoring protocol (No 1). Each finfish site operator is obliged to carry out monitoring of seabed conditions annually and these conditions are assessed against a fixed set of standards. In the 20 years since the initiation of the programme in 2000, monitoring reporting compliance (when the programmes were initiated) monitoring has ranged from 54 to 96% and environmental compliance within years has ranged from 50% to 100% compliant (Marine Institute Benthos Ecology Unit).

Similarly, the management of sea lice on salmon finfish operations remains an ongoing challenge for operators and regulators. The management programmes has evolved from the 1990's with the efforts of the Sea Trout Task Force to the publication of the Monitoring Protocol No. 3 and the Pest Management Strategy in 2008. The Marine Institute, and DAFM, monitor international developments in relation to sea lice management on an ongoing basis to ensure that appropriate management measures remain in place. Monthly inspection reports are circulated to relevant stakeholders, including eNGOs, and the annual report is published as an Open Access Marine Institute publication.

The sea lice threshold levels are in line with those applied in all other salmonid aquaculture jurisdiction. Thresholds were initially devised and approved by the Sea Trout Task Force which included a range of stakeholders. Due to a lack of empirical evidence on the direct effect of sea lice infestation levels and wild salmonid population levels, thresholds were devised by expert

[26] https://www.gov.ie/en/publication/fcd20-aquaculture-foreshore-management/#marine-finfish-protocols

opinion to be as close to zero as practically possible. Although other jurisdictions may have different management programme, they are all based on a standard threshold of number of lice per fish.

Should the lice threshold on farmed salmon be exceeded, the farm is instructed to act, which may result in treatment with chemotheraputents, accelerated harvesting or complete removal of stock, among other actions. In Ireland, the use of non-chemical treatment has increased. In 2020, the use of hyposaline water bathing for sea lice control became established on a number of farms. This delousing technique has been demonstrated to be an effective tool in the control of sea lice (Mc Dermott, et al., 2021). Thermal and mechanical delousing methods area also used in Ireland and are considered most effective at removing the mobile sea lice stages as opposed to attached lice stages (Grøntvedt, et al., 2015; Overton, et al., 2018).

5.2.2 Northern Ireland

The Agri-Food and Biosciences Institute (AFBI) undertake monitoring of shellfish aquaculture sites within Northern Ireland to ensure compliance of Habitat Regulations Assessment and Fish culture Licence conditions on behalf of the Marine and Fisheries Division of the DAERA.

In order to ensure that any changes in benthic sediments and communities remain small and localised, a programme of monitoring has been established for all new intertidal aquaculture sites within Northern Ireland granted in recent years. Baseline core samples and samples for Particle Size Analysis (PSA) are collected before the installation of trestles onsite (to be used as a baseline for future comparisons). PSA samples are collected monthly for analysis. If changes in sediments are detected, then further infaunal samples are collected for baseline comparison and management options explored.

In order to assess the ecological carrying capacity of aquaculture activities within Northern Irish Sea Loughs, to ensure the preservation of the habitats utilized by the species for which MPAs within the region are designated, the Sustainable Mariculture in northern Irish Lough Ecosystems (SMILE) model is currently being utilized by AFBI (https://www.afbini.gov.uk/articles/sustainable-mariculture-smile).

The SMILE model is a model used for the collation and processing of scientific information. Developed in 2007, it allows the application of an integrated framework for the determination of sustainable carrying capacity in the shellfish production areas for which it was developed (namely; Carlingford Lough, Strangford Lough, Belfast Lough, Larne Lough and Lough Foyle).

The SMILE model is currently being utilized by AFBI on behalf of local government departments to determine the ecological carrying capacity, the production carrying capacity and the cumulative impact of aquaculture activities within Carlingford Lough.

Using Chlorophyll a (Chl a) as a proxy for phytoplankton biomass the SMILE ecosystem model can determine the degree to which aquaculture species reduce the overall ecosystem phytoplankton biomass and hence food availability for other organisms within Carlingford Lough. This can therefore be utilized by government departments when considering applications for new aquaculture sites within the Lough as the model can simulate the impact on the ecosystem of increasing the abundance of filter-feeding organisms in Carlingford Lough. For further information on the SMILE model see Ferreira *et al* (2007).

5.2.3 Scotland

When a fish farm is licenced, its impacts continue to be monitored by a number of bodies. Many of these monitoring and survey reports are available online:

- Scotland's Aquaculture Website[27] brings together regulatory data collected by SEPA, Marine Scotland, Food Standards Scotland and the Crown Estate including site details, survey results and escape incidents
- Marine Scotland's Fish Health Inspectorate publishes information relating to its inspection and operational activities on its web pages on a regular basis[28]
- SEPA publishes details of compliance with licences issued under CAR as part of its compliance assessment scheme[29]
- The Scottish Salmon Producers Organisation (SSPO) publishes quarterly and annual Fish Health Management reports[30]

[27] http://aquaculture.scotland.gov.uk/

[28] https://www.gov.scot/policies/fish-health-inspectorate/

[29] https://www.sepa.org.uk/regulations/authorisations-and-permits/compliance-assessment-scheme/

[30] https://www.salmonscotland.co.uk/facts/fish-health-welfare

6 Ecosystem/Environment Interactions

6.1 Introduction

This chapter is arranged by the cultured species and their interactions with the environment within the Celtic Seas ecoregion, the implications of their location will be mentioned within each section. Climatic variation over the latitudinal range of the Celtic Seas means that local environmental conditions can vary. In the southwest of Cornwall at the southern end of this area, the annual sea temperate range is 9.7 to 17.1 °C, and in Shetland at the northern end the range is 8.2 to 13.1 °C. (https://www.seatemperature.org/ based on daily satellite readings from NOAA). Consequently, any potential interactions between aquaculture and the environment within the Celtic Seas ecoregion could differ depending on species and/or location.

There are several different countries within the ecoregion subject to a number of legal jurisdictions: Ireland, England, Northern Ireland, Scotland and Wales. Each have their own environmental governance regulations and strategies and consider environmental interactions of aquaculture in a different manner. Throughout the Celtic Seas ecoregion, the main species cultured within the marine environments are salmonids (Atlantic salmon and rainbow trout, and some Atlantic halibut), bivalves (blue mussels, Pacific oysters, European/native oysters, and King and Queen scallops), and some seaweeds. Each have distinct interactions with the marine environment and wider ecosystem largely resulting from their production methods.

6.2 Salmonid farming

Being anadromous, the adult stage of salmonid production is carried out within marine environments. Normally, this is within sea pens in inshore and open coastal environments, ranging from a few hundred tonnes to 3000 tonnes standing biomass. Both Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) are farmed, though the majority of the fish produced are salmon (See Chapter 2).

Salmonid farming within sea pens are intensive systems using artificial feeds. This can lead to a number of interactions. Growth of fish in close proximity, as for any animal-based farming system, also has the potential to incubate disease that require either physical or chemical treatments. Contained farmed fish may also escape due to failure of equipment.

As a consequence, there are a number of interactions between salmonid production and the wider environment, due to; excess nutrient release (dissolved and particulate), release of chemical treatment wastes, disease interactions (bacterial, viral and parasitic) with wild stocks, and potential genetic introgression between escaped farmed and wild stocks. In addition, the physical presence of the net pens systems can lead to possible environmental interactions, such as attraction for marine mammals. In this chapter these interactions are discussed briefly in the context of the Celtic Seas.

6.2.1 Nutrient wastes

One of the primary and most documented impacts on the local and wider ecosystems from marine fish pen culture is the effect of release and distribution of excess nutrients. These can be both soluble and particulate in nature and result from excretion, faecal release and deposited uneaten food (Beveridge, 2004).

Local impacts from particulate wastes are often site dependent and relate to the dispersive nature of the water flow within the area. Particulate nutrients mostly settle to the seabed within the vicinity of the fish farm, creating zones of effect on sediment biodiversity. Conditions and severity of effect change within seabed sediment "downstream" of the fish farm in the main tidal flow directions. Impacts can occur through smothering by deposited material or the incorporation of elevated levels of nutrients into sediments. Nutrient enriched conditions often occur directly beneath the farm resulting in depleted oxygen conditions and a low benthic animal diversity. Benthic effects grade progressively with distance away from the farm achieving natural conditions within 200–1000 m away, depending on the hydrodynamics of the site and size of the fish farm (Kutti et al., 2007; Keeley et al., 2013, 2019). In fast-flowing conditions, finer faecal particles can disperse more widely and found up to 2 km from the farm (Woodcock et al., 2018; Keeley et al., 2019). Impacts of nutrient wastes on the seabed over a wide area, in Scotland and Ireland, are managed and remain localised due to statutory annual or biannual monitoring (normally at the time of peak biomass) and reporting to the local environmental regulatory authorities; the Scottish Environment Protection Agency (SEPA), the Agri-Food and Biosciences Institute (AFBI) in Northern Ireland, and the Marine Institute in Ireland. Here levels of impact beyond environmental quality standards can mean non-compliance to regulation, leading to mitigation action that can include a decrease or prevention of future fish production. In Scotland, fish production, chemical treatments and environmental monitoring reporting for all production sites are available online. See https://informatics.sepa.org.uk/MarineFishFarm/.

Figure 6.1 shows the emissions reported and calculated for Scottish marine fish farming, 2005 – 2019. There is a consistent increase in nutrient (nitrogen, phosphorus, and total organic carbon) emissions in line with the increase in biomass and production over the period.

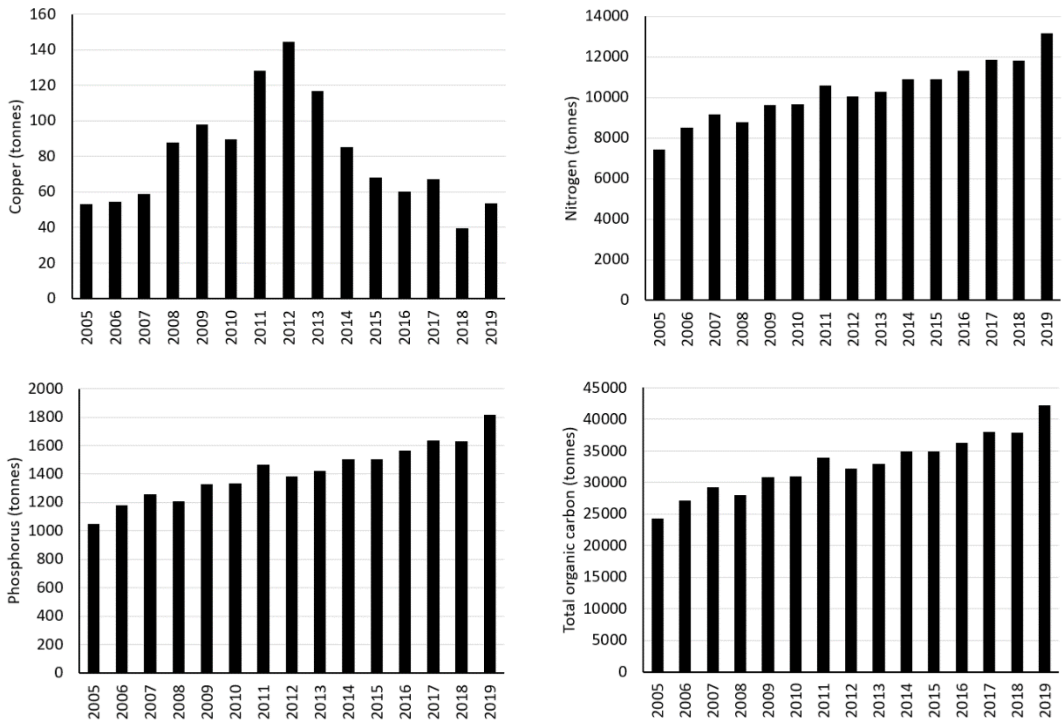


Figure 6.1 Total copper discharged and calculated overall nutrient emissions from Scottish fish farms, 2005 – 2019 (Scottish Government, 2021).

6.2.2 Disease interactions

The sea lice (*Lepeophtheirus salmonis* and *Caligus elongatus*) are a major parasite of cultured Atlantic salmon, and the most abundant parasite to affect farmed salmonids. It is widely distributed throughout most farmed salmon producing countries, including Scotland and Ireland where it causes multi-million-pound commercial losses to the salmon aquaculture industry (Costello, 2009). Its life cycle includes free-living life stages, and life stages attached to fish (Costello, 2006), though it is heavily affected by water temperatures, making it more abundant in summer and autumn months. Treatment in open-sea net pens is needed to keep lice numbers down and is achieved using a variety of methods using bath and infeed dosed chemotherapeutants (Barrett, et al., 2018), physical treatments that remove lice, such as the Thermolicer® (Grøntvedt et al., 2015), and biological control, such as use of cleaner fish (Brooker et al., 2018).

Existing studies in other salmon producing countries have shown that sea lice infestation of young salmon leaving the river (smolts) can affect the numbers of wild salmon returning to rivers (Bøhn et al., 2020; Serra-Llinares et al., 2020). Many factors can influence the extent to which sea lice may affect wild salmon populations, such as the size of the fish, the distance and the areas through which salmon smolts migrate when heading to open ocean, the distribution of sea lice due to farms, sea lice control measures on farms and the status of local wild salmon populations. Therefore, impacts in one country or region do not necessarily apply to others.

Currently there is little information on the impact of sea lice from aquaculture on wild salmon in Scotland, however, the Scottish Government, through Marine Scotland, is engaged in a ten-year research programme to investigate potential risks to wild salmon from sea lice in the Scottish coastal environment. The Scottish industry report lice numbers on production fish weekly, and data are publicly available on a website. In Ireland, using a meta-analysis of combined data, Jackson et al (2013) concluded that though sea lice-induced mortality on outwardly migrating salmon smolts can be significant, it is considered a minor and irregular component of wider marine mortality in the stocks studied and is unlikely to be a significant factor influencing conservation status of wild salmon stocks. However, in Norway data suggests significant interactions between sea lice and wild salmonids (Halttunen et al., 2018), and consequently interactions from a large part of the risk assessments and implementation of a 'traffic light' regulatory system (Bailey et al., 2020), that is currently subject to review (Norwegian Research Council, 2021).

There is potential for transmission of other disease vectors between farmed and wild stocks, in particular Infectious Salmon Anaemia (ISA) and Pancreatic Disease (PD). Outbreaks of ISA are few and once identified are subject to rapid mitigation. In Scotland, outbreaks are contained by; compulsory slaughter and disinfection of infected farms, strict movement controls on suspect farms, and placing farms in the vicinity of an outbreak under surveillance (Scottish Government, 2019). Cross infection of ISA and wild fish can occur as occurred during an outbreak of ISA in Scotland in 1998–99, testing of wild salmonids indicated that there were positive samples near to the infected farms (Raynard et al., 2001). Similar results were found in Norway (Nylund et al., 2019). PD or infectious pancreatic necrosis is a viral disease affecting mainly fry (juvenile) salmonid stages, though all age groups can be affected. Mitigation is currently through testing and control, though vaccine development is underway. Yet limited, there is a prevalence of PD in both wild and farmed salmon when outbreaks occur (Ruane, et al., 2007).

Risk assessments on change in occurrence of ISA and PD have been conducted in Norway. They conclude that as outbreaks of ISA are few and good mitigation measures are in place risk in change of disease status in the is low. Where occurrence of PD is more frequent the risk of change is considered moderate. No such assessment has been done for the Celtic Seas ecoregion.

6.2.3 Escapes

Escaped farmed salmonids can both compete with wild fish for resource (food and breeding space) or interbreed with wild stocks causing genetic introgression. The extent of this impact is difficult to quantify and so assess the overall risk. Literature on the subject often gives conflicting impressions and more research is clearly needed.

An example of escape of farmed salmonids within the Celtic Seas ecoregion can be taken from Scotland, which uses mainly Norwegian salmon strains. All incidents of escapes are statutorily reported under regulation and publicly available (Scottish Government, 2022). Figure 6.2 presents total reported annual escapes from Atlantic salmon farms between 2000 and 2021.

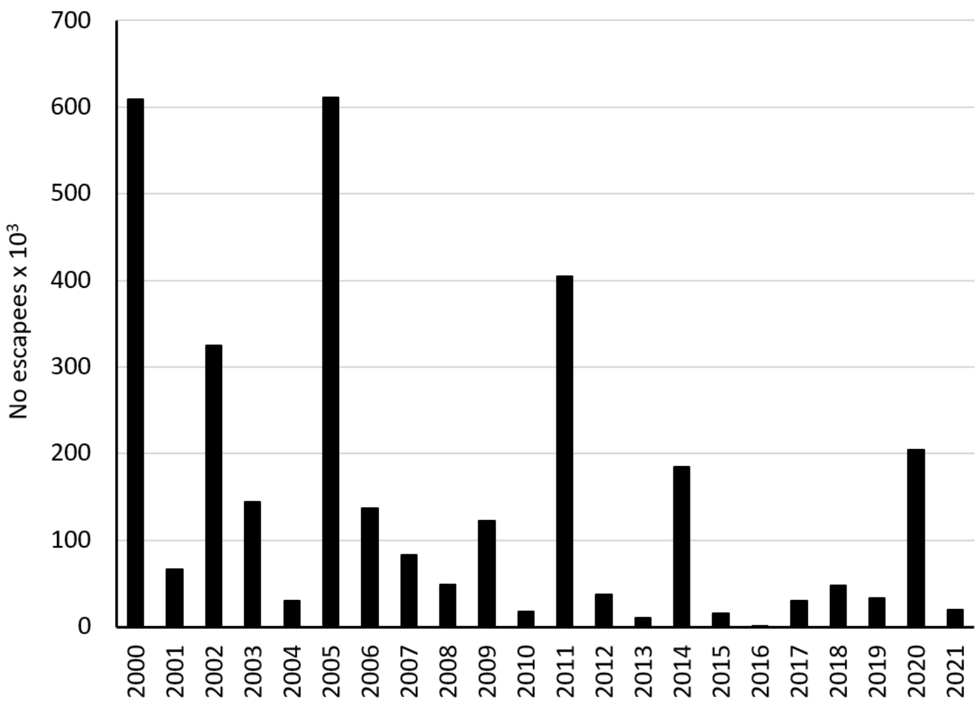


Figure 6.2 Reported escaped Atlantic salmon from Scottish farms, 2000 to 2021 (Scottish Government, 2022 – http://aquaculture.scotland.gov.uk/data/fish_escapes.aspx)

Though the numbers per year are highly variable and dependent on a number of environmental and management factors, the number of escapes has decreased recently; for example, the mean number between 2000–2010 is 199,570 fish, and mean number between 2011–2021 is 89,934 fish. This suggests that farm practice and management are improving with time and technological advances, so lessening the risk over time of short-term competition for resources between farmed and wild fish. No significant escapes have been recorded in Ireland in recent years. This may be a response to revised structural design protocol[31] applying to net pen design and construction.

Information on interactions is often contradictory. A study by Green et al (2012) used reported escapes data for Scotland with anglers' counts of caught farmed Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*). Statistical models found that no robust association was found between documented escape events and larger proportion of farm origin salmon in anglers' catch,

[31] https://www.gov.ie/en/publication/fcd20-aquaculture-foreshore-management/#marine-finfish-protocols

nor with overall catch size. A recent assessment by the Scottish Government of the influence of farmed salmon escapes in Scotland (Gilbey et al., 2021) found that of 252 freshwater and marine sites examined, 237 were classified from good (no genetic changes observed) to very poor (major genetic changes detected). Overall, the classification throughout Scotland found 182 (77%) sites classified as good, 21 (95) as moderate, 20 (8.4%) as poor and 14 (6%) as very poor, see Figure 6.3. However, genetic integrity of populations within the results was not uniform and signs of genetic interaction were concentrated in some areas of marine aquaculture production and freshwater smolt rearing.

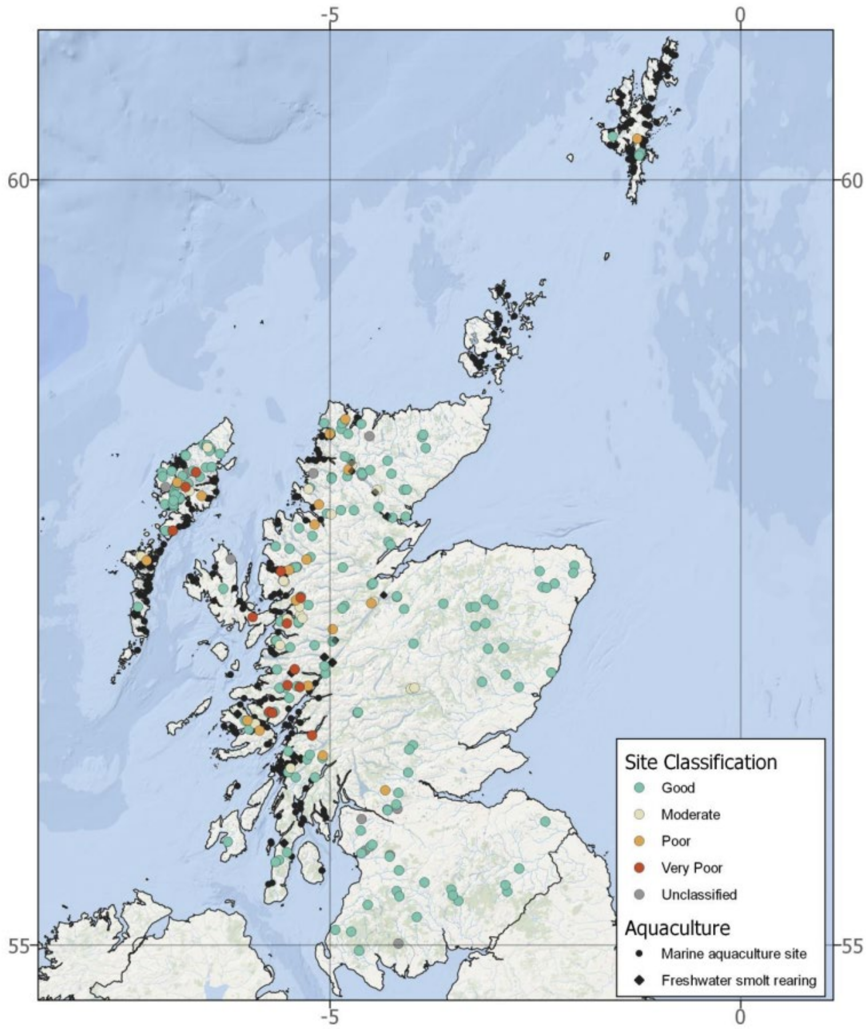


Figure 6.3 Site classification of the genetic status of sampled wild salmon across Scotland in relation to aquaculture production facilities in the marine and freshwater environments (reproduced from Gilbey et al., 2021).

The report concluded that there is evidence that introgression of genetic material from Norwegian farm salmon strains has altered the genetic composition of some populations within rivers near marine aquaculture production, and that this information can be used for effective management in future.

6.2.4 Chemical treatments

A number of chemicals are used or therapeutic treatment of disease or maintenance of structures when farming salmonids in coastal net pen systems. Therapeutants are primarily used for the treatment of bacterial diseases (antibacterials) or against parasites. Anti-sea lice compounds are the most commonly used chemical treatment in the ecoregion. They are used in two forms, bath treatments dosed in liquid form in a contained pen or in an isolated facility within a large boat, and infeed treatments that are formulated in the feed and ingested. Much of the bath treatment currently is completed within a 'well-boat' where residue chemical from the treatment is treated or discharged in an approved area, often some distance from the farm and usually when the boat is in motion to increase the environmental dilution (Parsons *et al.*, 2020). Each production site in Scotland, Northern Ireland and Ireland has a maximum level of treatment that can be used over a period, usually a year.

In Scotland, treatments and the amounts used at each site are recorded and publicly available from 2002 to date (see https://informatics.sepa.org.uk/MarineFishFarm/). These data shows the changing use of different treatments over the past 20 years, Figure 6.4. Figure 6.4A shows a consistent use of emamectin benzoate (SLICE) since 2002, conversely after significant use of teflubenzuron (Calicide) in 2012–13 none has been employed since. Figure 6.4B shows use of relatively small amounts of deltamethin (Alphamax) since 2008 to present and for cypermethrin (EXCIS) between 2002 and 2010 though none is used since. There was an increase in use of azamethiphos (Salmosan) between 2007 to 2016. As can be seen the key treatments for sea lice in Scotland are currently emamectin benzoate and azamethiphos. Hydrogen peroxide (Paramove) is also used as a bath treatment for sea lice and amoebic gill disease (another parasitic disease) in Scotland and Ireland.

Effects of these treatments can occur on non-target species when they released into the environment, after treatment or within uneaten food of residues in faecal materials, though the specific effect is highly dependent on the sensitivity to the species (Urbina *et al.*, 2019, Parsons *et al.*, 2020). Bath treatments have potential to affect the pelagic environment, and in particular the zooplankton which are an important part of the coastal foodweb. Hydrogen peroxide is often considered environmental benign due to rapid oxidation into water and oxygen, though very localised impacts after treatment may occur. Infeed treatments can accumulate in sediments beneath or near to the farm (up to 30–50 m away), though sometimes further (Samuelsen *et al.*, 2015). When entering the environment, they bind to organic material and are often stable within the sediments allowing concentrations to accumulate. In Scotland and Ireland residuals for infeed treatments are monitored within sediments to conform to a designated maximum allowable level.

Biofouling can be an issue for large coastal structures and add to stress leading to failure. In order to prevent this on net pens, anti-biofoulants are used in the form of paints and coatings or are removed mechanically. The main active antifoulant ingredient used in these coatings is copper (Cu), which leaches out to prevent settlement. It has been estimated that 80% of the treatment leaches into the adjacent water column between coatings (Solberg *et al.*, 2002). Total Cu emissions in Scotland are reported for each coastal farm, though this also includes the Cu in the feed (http://aquaculture.scotland.gov.uk/map/map.aspx). In 2019 to total Cu released into Scottish coastal waters from fish farms was 53,468 kg. Figure 6.1 shows the variation in Cu emissions 2005–2019. Copper use as antifoulant treatment though peaked in 2012 and have decreased in use since.

It should be noted that there is no official data recorded on methods used to control sea lice in Ireland. The use of chemotheraputents is carried out under veterinary supervision and records are subject to review by authorised officials. However, it is noted that use of non-medicinal treatments are becoming more common (see Section 5.2.1).

Figure 6.4 Total amounts of anti-lice treatment used in Scotland, 2002 – 2021. A) Infeed treatments, B) Bath treatments (SEPA, 2022).

6.2.5 Marine mammals

Marine mammal populations within the Celtic Seas inevitably interact with finfish farms to some extent, and these interactions can be negative to both the mammals themselves and the aquaculture industry. The most significant and problematic of these interactions occur between finfish farms and seals. Using Scotland as an example, there is a population of around 122,500 grey seals (83% of the UK population), and around 26,900 harbour seals (82% of the UK population) (Scottish Government, 2019). Predation by seals is an economic and welfare concern to the fish farms, and potentially lead to escapes of farmed salmonids (Jackson *et al.*, 2015). This interaction has led to lethal removal of seals, which has been regulated since 2011 in Scotland, and this is now no longer an allowed method of control. The key interaction now between seals and fish farms are deterrent methods such as acoustic deterrent devices (ADDs) and tensioned cover netting. These are used widely, but it is recognized that ADD they may cause disturbance to cetaceans under certain conditions (Mikkelsen *et al.*, 2017). However, interactions between salmon farms and marine mammals more broadly are poorly understood (Heredia-Azuaje *et al.*, 2021). In Ireland, under Section 42 of the Wildlife Act 1976 (as amended), an operator may apply to the minister to take certain measures to stop the damage to aquaculture installations. Such measures include shooting seals. In 2019, a Section 42 permission issued for a fish farm was for 1 Grey Seal in Co Mayo. None were issued during 2018 and 2017. Two licences were issued in 2016 one for County Mayo, for 1 grey seal and one for County Galway for 2 harbour seals. It is unknown if any seals were actually killed on foot of these licences (Wildlife Licencing Unit, National Parks and Wildlife Service – personal communication).

6.3 Bivalves

Bivalves are grown throughout the Celtic Seas ecoregion. There are two main species grown, blue mussels (mainly *Mytilus edulis*) and Pacific Oysters (*Crassostrea gigas*). Other species grown, include European or native oyster (*Ostrea edulis*), the King and Queen scallops (*Pecten maximus* and *Aequipecten opercularis*). Mussels and oysters can be grown from floating lines in coastal waters or on the shoreline in managed areas or on pallets. Scallops are often collected from managed areas or grown in lantern nets suspended from floating structures. More scallops are fished through dredging or collecting using divers than cultured in this area, and environmental interactions of this fishery is beyond the scope of this review.

Bivalves as filter-feeders consume plankton and particulates from the water column. This means they are extractive and have different nutrient-based environmental interactions within the coastal environment than fed aquaculture. This can be exemplified by looking at mussel culture.

Several studies have shown that mussel farming has a relatively small environmental impact compared to fish farms and animal production on land (Folke and Kautsky 1989, Jonell *et al.*, 2013, Aubin *et al.*, 2017). However, mussel farming can have negative effects, in particular when the farms are large and dense (e.g. Burkholder and Shumway, 2011).

Over the mussel farming cycle, only about 25% (5 – 45%) of the nutrients contained in the plankton and organic matter consumed by the mussels are removed at harvest (Folke and Kautsky 1989, Cranford *et al.*, 2007, Brigolin *et al.*, 2009, Janssen *et al.*, 2012) – see Figure 6.5. About one third of the nutrient eaten (30%) settles to the seabed as faecal and pseudofaecal material, increasing local nutrient levels and enhancing sediment productivity. About 45% is excreted as dissolved nutrients and carried away by currents, potentially changing the N/P ratio (Kautsky and Wallentinus, 1980; Kautsky and Evans, 1987), which may affect the balance in the plankton community. Production of faeces and pseudofaeces is at its highest during summer period and can increase sedimentation rate and organic load beneath the mussel lines between 70–150 times compared to the natural sedimentation rate (Kautsky and Evans, 1987) for an average sized mussel farm (60 tonnes biomass). This redistribution of nutrients can have impacts on the local benthic environment. Though, the effect on nutrient cycling depends both on how the farm is set up (e.g. density of mussels) and on local environmental conditions (e.g. depth, sediment type, water flow). They also have potential to contribute to enhancement of biodiversity in the area (Sheehan *et al.*, 2019)

7 Social and Economic Context

7.1 What, Where and How?

Headline figures in 2018 indicate that overall aquaculture production in Europe produced 1.1 million tonnes of live weight product worth approximately 3.7 billion EUR. Production from the Celtic Seas ecoregion during the same period represented 20.6% (227,000 tonnes) and 34% (1.27 billion EUR) of these statistics, respectively (EuroStat, 2020). As communicated above, aquaculture in the Celtic Seas ecoregion is primarily marine-based, occurring from the sheltered intertidal zone to exposed deep inshore waters. It is located within the various Bays and estuaries in coastal regions. The species farmed are mainly salmonid finfish and bivalve shellfish. While there are a small number of inland finfish production units and several land-based shellfish hatcheries in all countries, the focus of this section will be on species culture in open marine systems. In the ecoregion, the value of marine aquaculture outputs reflects the combination of statistics from both the UK and Ireland.

Data sources

Information for this section is derived primarily from industry surveys carried out by state agencies. These surveys form the basis of a number of important national and international economic reports on the aquaculture sector in the countries in question (BIM 2022, STECF 2021, Munro, 2021). What has complicated the presentation of data is the departure of the UK from the EU (Brexit) and hence, the majority of statistics for comparative purposes are derived from 2018 (the last year of combined statistics as presented to EuroStat). Furthermore, the majority of the data presented represent broad characterization of the sectors within each reporting jurisdiction (i.e. mostly separated according to marine finfish and shellfish sector statistics only).

7.2 Scale/Capacity

During 2018, 275 and 251 enterprises were recorded as operating in marine aquaculture in Ireland and the UK, respectively (Table 7.1). In Ireland, the majority of businesses and their production units are considered small, employing less than five persons. Similarly, for the UK small units predominate. However, in both countries, more capital-intensive operations (i.e. primarily the finfish sector) tend to operate multiple production units and employ considerably more people per enterprise. There has been an overall shift from fewer of the smallest PU size category operating in the face of pressure to operate businesses full-time and to move towards more capital-intensive production. This can be clearly seen in the rope-mussel sector and less so in the oyster sector in all countries.

In the UK, the salmon industry employed 55% of people in the aquaculture sector whereas, in Ireland, it constitutes 11.5% of the sector overall. The increase in employment in the overall aquaculture sector since 2008 has been 3% in the UK and 6% in Ireland. In Ireland employment in the shellfish sector remains static (approx. 1700 persons) while the finfish sector has gradually increased year-on-year. Similarly, the finfish sector in the UK has seen small growth in employment numbers in the same period whereas the shellfish sector has declined slightly. Of note, the number of FTE in the salmon sector in Ireland is 171 representing 76% of the overall employment numbers for the sector. Whereas the shellfish sector FTEs (at 778) is 46% of those employed. The UK has stronger relationship for marine salmon production with FTEs representing 91% of those employed. For shellfish the proportion of FTE to those employed is considerably lower at 35%.

The stability over time of these employment statistics in both jurisdictions are important and speak to the resilience of the industry. Similarly, the ratio of FTE to employment statistics in the shellfish sectors indicate that the sectors rely heavily on part-time employment and, given the locations (i.e. rural and more isolated regions) this avenue for employment is considered an important economic contributor to these areas as borne out by the positive gross value added statistics (Table 7.1) from both jurisdictions (BIM 2022, Hynes *et al.*, 2021). Typically, in the shellfish sectors, employment include large part-time and casual components. In previous years hiring labour for short periods and pay cash in hand and it was economically feasible for such workers to work in such manner. However, employment law now dictates that all workers be accounted for, no matter how brief their employment, and therefore, casual labour is less economically attractive and therefore harder to find. The rope mussel segment in certain bays and to a lesser extent, the farmed oyster segment is most affected by these tighter labour regulations.

Table 7.1 Summary economic and employment statistics for UK and Ireland aquaculture outputs during 2018 (EuroStat, 2020).

2018	UK	Ireland	Total
Enterprises			
Shellfish[32]	205	249	454
Finfish	46	26	72
Employment (overall)			
Employment	2560	1932	4492
FTE	2259	1070	3329
Sales Value (EUR) (x10^6)			
Finfish	1,000	119.6	1,119.6
Shellfish	32.1	58.2	90.3
Gross Value Added (EUR) (x10^6)			
Finfish	256.8	23.1	279.9
Shellfish	14.6	32.6	47.2

[32] The shellfish sector statistics in the UK are represented primarily by statistics from the dominant Mussel industry. In Ireland these statistics represent a combination of returns from oyster and mussel industries.

7.3 Issues and Trends

The major trends through 2017 and 2018 were that of continued steady growth for oysters and rope mussel production, the expected cyclical downturn in salmon production, due to the constraints of licenced production space, the up to 18-month production cycle and the demands of organic certification standards, uncertainty for the bottom mussel sector dues to seed supply issues.

Rope mussel and off-bottom oyster output continues to grow steadily. The rope mussel segment continues to amalgamate businesses and as a consequence will gradually shed employment. The farmed oyster segment, on the other hand, continues to increase its number of businesses and employment. The segment is slowly expanding its market base away from France to markets in the Netherlands, Italy, other EU states as well as Asia. Bottom grown mussel production continues to be relatively low and uncertain to predict, long term as there appears to be no sign of a re-emergence of the extensive wild seed beds that underpinned the greater production of this segment in the early 2000's. Both mussel segments are vulnerable in their market placements, relative to that of their competitors who are home suppliers of the market destinations.

The sectors in both the Irish and UK industries are export-driven. The organic salmon has heretofore been under-supplying the market and continues to be restricted by the constraints to increasing production.

In addition, new finfish aquaculture licences granted in Ireland, remain unused as their awards are appealed in protracted processes.

In Ireland, the total sector output, over the last 10 years, has varied between 31,600 and 44,800 tonnes, with a total farm-gate sales value between 116.1 EUR and 200 million EUR (STECF 2021). Unit sales value has steadily increased for the pen salmon and farmed oyster segments. Output volume and value are dominated by the cyclical nature of salmon production output which is governed by varying production time cycles, the fallowing and unit capacity requirements of organic certification and a shortage of available licenced sites. The farmed oyster segment has grown steadily in licenced capacity, output volume and unit sales value. The number of businesses in the segment are increasing. The rope mussel segment has remained at a consistently undulating output level, with market supply disrupted at times by closures in the face of red tides. Most if not all suitable sites for this segment, using current available techniques, are either already licenced or otherwise used. Businesses in the segment are consolidating. The seabed mussel segment has declined in output in recent years as the wild seed settlements it continues to depend upon for input stock have become increasingly scarce. The number of businesses in the segment is decreasing with amalgamation.

In the UK aquaculture production is dominated by salmon farming in Scotland where production is trending upwards. Salmon is Scotland's largest food export and the Scottish Government recognizes the contribution of aquaculture in helping to sustain economic growth in the rural and coastal communities and support (up- and downstream) jobs across Scotland and the catalytic effect of that income across the economy.

Despite the existence of aquaculture development plans, the main segments in other UK regions, i.e. trout and mussel, continue to decline. The only species other than salmon that is increasing production in the UK is Pacific cupped oyster; however, it is subject to continuing environmental scrutiny as a non-native invasive species. A new English Aquaculture Strategy was published in November 2020 which intends to catalyse growth within this region.

Further factors that may affect the future of UK aquaculture are:

- Sales prices – Salmon is a global commodity and prices are somewhat volatile responding to global supply and demand. The above analyses illustrate that differences between species in unit sales price and trends over time are a key determinant of profitability.
- EU-exit – A significant portion of UK aquaculture production is exported rather than being consumed domestically. Following the end of the transition period, on 01/01/21 a new Fish Exports certification process was launched; "teething problems" associated with documentation have been experienced by seafood exporters to the EU early in 202136 37 38. An additional potential issue for UK bivalve producers are EU hygiene regulations preventing export of live shellfish from the UK which require depuration; depuration facilities within the UK are limited and such shellfish had previously been sold for depuration at large plants within mainland Europe.
- Grant funding - Although aquaculture enterprises have lost access to EU EMFAF funding for aquaculture development, new domestic funding schemes have been introduced.

A number of environmental/ecological concerns in the UK salmon sector are identified in common with Ireland and continue to occupy the regulatory authorities as well as the salmon industry. These issues are well recognized and are considered in more detail in Chapter 5, above. In short, they relate to parasites, pathogens, algal blooms, jellyfish swarms as well as escapes and contaminant release into the wider environment. Management of these factors will contribute to variability of annual production volumes. The lack of social licence relating to the industry (particularly the salmon sector) is a major constraint to the operation and management of this sector and other aquaculture sectors considered guilty by association. The industry in both the UK and Ireland continues to be challenged by lack of acceptance among certain NGOs, academics and private individuals who will challenge the licencing process. Their concerns relating to environmental and ecological impacts (see Chapter 8) are continually highlighted as are the perceived lack of regulatory oversight. Licencing and regulatory bodies obviously take a different view and will cite stringent risk assessment process during licencing deliberations and subsequent regulation of operations.

Although aquaculture in other UK regions is considered less important, the potential for sustainable seafood production in the wider UK is considered high as long as a number of environmental concerns can be adequately addressed. As with Ireland a prominent issue is consideration of the potential interactions with conservations (Natura 2000) sites. Specifically, evaluations of interactions with bird species continues to be constrained by lack of empirical data on responses and methods to assess these interactions. Ongoing work in the UK and Ireland on utilization of food resource modelling in intertidal areas will hopefully advance knowledge in this area.

8 Interaction of environmental, economic and social drivers

8.1 Environmental, economic and social drivers of aquaculture

The development and management of aquaculture activities are driven and influenced by many factors which can be country-specific, and can vary at the local, regional and global scale. Krause and co-authors (2015) grouped the drivers of aquaculture into 3 main categories: ecological, socio-economic, and institutional.

Ecological drivers

These include environmental quality, climate and ecological functions. Climate change (and adaptation to change) is a strategic challenge faced by aquaculture, not just in the Celtic Seas ecoregion but also globally. Climate change can affect aquaculture activities via changes in sea level rise, storminess and waves, air and water temperatures, ocean acidification and terrestrial rainfalls (Garrett et al. 2021). Considering, for example, the UK finfish and shellfish aquaculture, air/sea temperature change and change in rainfall/run-off are climate drivers that are expected to lead to priority impacts (although ocean acidification is also relevant to shellfish production; Garrett et al. 2021). Changes can affect farmed organisms directly (e.g. higher temperature can affect growth) but also indirectly (e.g. warmer conditions can increase problems such as sea lice, fish disease, shellfish pathogens, harmful algal blooms and jellyfish blooms; Garrett et al. 2021). These drivers can have negative implications for aquaculture (i.e. maintenance of existing species; undermine of spat collection; closing of some collection/farming areas) but also positive (i.e. opportunity to cultivate novel species; opening of new collection/farming areas; Garrett et al. 2021). Another ecological driver of aquaculture is the provision of ecological functions or services. Particularly for seaweed and shellfish bivalve aquaculture there is growing evidence of the ecosystem services provided by these forms of aquaculture, such as provision of habitat for other organisms and bioremediation (carbon and nutrients uptake), as well as the ability to support achieving the UN Sustainable Development Goals (see review by Duarte et al. 2021).

Socio–economic drivers

There are multiple socio–economic drivers including production factors, technology, market, culture, know-how, and equity. Market (also including proximity to market and transport links; Little et al. 2013) and consumer preferences can drive demand for particular species. National and international demand for certain categories of seafood can be linked to depletion of global fish stocks but also to consistent quality, supply and price of farmed seafood (Little et al. 2013) Extractive species (such as seaweed and shellfish bivalve) could be favoured by consumers due to their lower carbon footprint during production, compared with other forms of aquaculture or agriculture (Hilborn et al. 2018). At the same time development of new value chains such as production of biofuels or bioplastics from seaweed biomass could increase demand for macroalgae biomass. In terms of technology, engineering improvement to the farm structure for cultivation in exposed sea areas, or mechanization of harvesting may support an expansion of the industry in offshore areas and with larger farms. Cultural drivers can also be important; for example, coastal rural communities can look at bivalve cultivation as a way to remain in their familiar local environment, carrying out a job that sustain a healthy food production and healthy coastal environment (Krause et al. 2019).

Institutional drivers

These include policies, governance, laws management scales and rules, stakeholders, and ownership (where the latter refers to the right of using the good, earn income from it, etc.). National and regional aquaculture strategies (such as the one for Scotland Aquaculture Growth 2030.pdf (salmonscotland.co.uk) and England English Aquaculture Strategy from Seafood 2040 — Seafish), set up clear targets for aquaculture development and production in the short-medium term. These, combined with funding schemes (e.g. UK Seafood Scheme https://www.gov.uk/guidance/uk-seafood-fund; Fisheries and Seafood Scheme https://www.gov.uk/guidance/fisheries-and-seafood-scheme) could drive and support the development of the industry. Actions and policies outside the immediate sector (e.g. governance of water and land development; Little et al. 2013) can also have impacts on aquaculture in coastal, inshore waters.

8.2 Environmental, economic and social interactions

Aquaculture activities have the potential to cause significant social, economic, and environmental impacts through upstream and downstream links (for example using chemicals, wastes expelled, stock migration), therefore impacting different stakeholders (Little et al. 2013). These interactions or impacts could be positive or negative, direct or indirect. In terms of socio–economic interactions, aquaculture brings employment along the value chains of aquaculture products, as well as benefits to many people, both directly and indirectly involved in the farming activities (Little et al. 2013). Aquaculture can also have indirect interactions, for example when farming activities results in a negative environmental impact (e.g. release of chemicals or waste) which can affect other activities in the area or proximity (e.g. other forms of aquaculture, recreation). Chapter 5 and 7 of this report provide a detailed description of the environmental and socio–economic impacts of aquaculture in the Celtic Seas ecoregion, therefore this section will focus on reviewing the main interactions of aquaculture with other activities (under an environmental, social and economic point of view).

In the coastal and offshore marine space, aquaculture interacts with multiple other activities under different environmental, social and economic aspects. Interactions between aquaculture and fisheries include displacement of fishers from fishing grounds when used for aquaculture, occurrence of sea lice and parasites from farmed to wild stocks, interactions of farmed species with wild and migratory fish. A recent study (Nimmo et al. 2022) commissioned by the Crown Estate Scotland, reviewed the main interactions between shellfish and seaweed aquaculture and static commercial fisheries in Scotland. The main conflicts identified included: exclusion, access and displacement (due to presence of aquaculture); snagging and infrastructure damage (e.g. entanglement of pots with aquaculture ropes, gear trawled through aquaculture sites); changes to the local environment (e.g. attraction/displacement of adults fish; consumption of fish eggs/larvae by farmed organisms); pressure on land-based resources including harbour facilities, lack of involvement of fishing sector in site selection for aquaculture development; potential indirect competition between market products and by-products (Nimmo et al. 2022). Interestingly the same report also identified potential mutual benefits or positive interactions between aquaculture and fisheries including multi-use of marine space (aquaculture facility allows access to commercial fishing vessels); shared facilities and infrastructure; improvement access to land-based access points; employment (e.g. fisher can provide vessel services); knowledge transfer and common market development. As shown by this study, the interactions between aquaculture and capture fisheries (both positive and negative) cover environmental and socio–economic aspects, and part of them could be managed by closely involving fishers during planning and developing stages of aquaculture facilities.

Another area of potential interaction is between aquaculture and tourism / recreation (e.g. boating, recreational fishing, swimming). The interactions between aquaculture and recreational users could be negative, such as access restrictions to specific sea areas due to the presence of aquaculture activities or visual impact of the farm (e.g. mooring structure at the surface), or through negative effects on the marine environment or wildlife (e.g. Mikkelsen et al. 2021 and references within). However, interactions could also be positive, for example if the farm becomes a wildlife hotspot (e.g. attracting birds, marine mammals) for recreational users, and by providing high quality seafood products for tourists (Project Ireland 2040 National Marine Planning Framework[33]).

Aquaculture can have environmental, social and economic interactions with other activities such as shipping, dredging, and renewables (e.g. wind farms) etc. While some of these activities may not be 'compatible' with aquaculture and may act as exclusion areas for aquaculture (e.g. major navigation routes), others can coexist with aquaculture (e.g. offshore renewables). Although there are no examples of co-location between aquaculture and offshore renewables in the Celtic Seas ecoregion, multiple studies and pilots have been carried out, for example, in the southern part of the North Sea, during projects such as the EU FP7 MERMAID (Home (vliz.be)) or the current H2020 UNITED (About (h2020united.eu)) and INTERREG VA Wier & Wind (Project - Wier & Wind (keep.eu)). Aquaculture and offshore renewables are quite different (e.g. in terms of capital and operations costs, spatial extent, maintenance) but they can share common use of forecast and warning systems, accommodation platforms and potentially staff (Go offshore 2014 report[34]). Direct socio–economic impacts of co-location of offshore renewables and aquaculture would relate to earning capacity and costs for employees and families of both industries, as well as suppliers, while indirect impacts would be related to impacts on consumers and the broader economy. In terms of environmental interactions, a reduction in wave attenuation due to presence of aquaculture within an offshore wind farm may reduce fatigue load on the turbines and extend the weather window for operation and maintenance activities (Go offshore 2014 report).

Another important interaction is between aquaculture activities and conservation (i.e. protected areas). Aquaculture is not excluded a priori in protected areas; however appropriate assessments (e.g. Environmental Impact Assessment, Habitats Regulation Appraisals) need to be carried out to verify that the conservation objectives are not compromised by farming activities (Le Gouvello et al. 2017). The species being considered for cultivation and the associated farming method are very relevant in this context, as farming of seaweed, shellfish or finfish have different environmental impacts. For example, offshore mussel farms may enhance commercial and non-commercial fish species producing a spillover effect in the areas surrounding the farms, as well as restoring benthic habitats within the farm (see review by Mascorda Cabre et al. 2021 and references within), therefore serving a similar role as marine protected areas (see review by Mascorda Cabre et al. 2021).

[33] https://www.gov.ie/en/publication/60e57-national-marine-planning-framework/

[34] https://www.vliz.be/projects/mermaidproject/docmanager/public/index.php?dir=Outreach_Material%2F&download=MERMAID_Go_offshore_Combining_food_and_energy_production.pdf

The National Marine Planning Framework (Project Ireland 2040) also identified eutrophication as one of the interactions with aquaculture. Although eutrophication is not an activity per se, it is the result of other activities mainly land-based such as agriculture, discharges from unsewered areas and industry. In this case the reduced water quality (presence of toxic algae blooms, reduced oxygen concentration in the water) can have adverse impacts on aquaculture activities, although, on the other hand, aquaculture of seaweed and shellfish bivalve may help bio-remediating eutrophic areas.

8.3 Aquaculture planning to manage environmental, economic and social interactions – case studies

The previous sections and chapters highlighted that aquaculture could have multiple environmental and socio–economic impacts and could interact with numerous other activities. When planning the development of new aquaculture facilities (or the expansion of existing ones) all these factors need to be considered, to ensure aquaculture is carried out in a sustainable way, reducing conflicts with other activities, without impacting on protected marine features and engaging relevant stakeholders. Decision support tools for development/expansion of aquaculture are often based on models (for lists of these models, see TAPAS https://www.aquaculture-toolbox.eu/modelling-tools/ and Ross et al. 2013). Models or virtual technologies (e.g. GIS, remote sensing) can help identify areas with suitable environmental conditions for a given species, and can simulate interactions between farm(s), the surrounding environment and other activities, under different scenarios that could be challenging, expensive or dangerous to simulate in real world (Ross et al. 2013).

Ross and co-authors (2013) classify these models into broad groups:

- environmental models: simulate environmental changes associated with farm activities, including quality of the water (e.g. nutrient loads and waste), to minimized death of farmed organisms and predict profitability; they require data on depth, currents, feed inputs, and can be used by regulators to assess environmental impacts;
- dynamic models: similar to environmental models in the sense that they focus on how the environment responds to different siting and production levels, but they can also show changes over time;
- production models: simulate production of the farm including ecological and economical optimization of the farm, as well as optimization of farming methods.

During the spatial planning process, it is key to incorporate stakeholder' views and inputs (social drivers) on the output of ecological and production models; this can be based on perceptions and may be non-quantitative. The resulting discussion will allow to integrate ecological, production and social implications, highlighting trade-off of aquaculture activities at a particular location.

This section provides four examples (case studies) of applications of tool for spatial planning of aquaculture in the Celtic Seas ecoregion: two in England (one at the local "county" scale and one at the wider "country" scale), one in Northern Ireland and in Ireland.

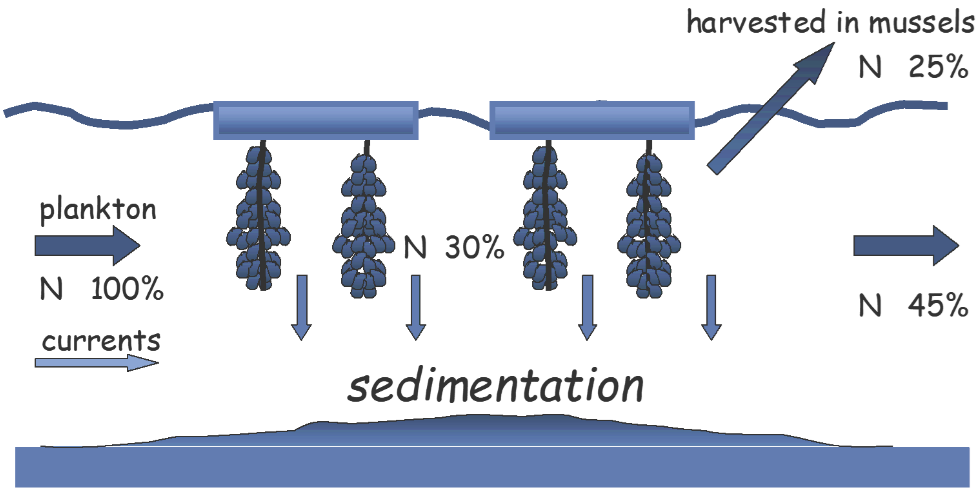


Figure 8.1 Reapportioning of nutrients from mussel farming (after Kautsky and Wallentinus 1980, Kautsky and Evans 1987, Folke and Kautsky 1989).

The mussel filtration impact on water clarity depends on seston particle composition, but also water retention time and the blue mussel biomass (Kach and Ward 2008, Nielsen et al. 2016, Schröder et al. 2014). However, increasing the number of mussels only leads to marginal improvements of water clarity, since there is an inverse logarithmic relationship between phytoplankton density and Secchi depth (Lorenzen 1980) and since particle removal efficiency of the mussels decreases logarithmically with particle concentration. This means that to improve water clarity from 0.5 m to 1 m, the farm must increase by many times. Intensification of mussel farming in order to improve water clarity may also lead to food limitation for the mussels in the farm (cf. Rosland et al. 2011) and since food-limited mussels grow less, this may ultimately lead to smaller harvests and less nutrients removed from the ecosystem than expected.

Although legally cultivated, wild Pacific oysters are classified as an invasive non-native species in the UK and there is a potential ecological risk associated with the growth of wild populations of Pacific oysters as a result of rising sea temperatures caused by climate change (Herbert et al., 2012). Consequently, the risk of negative environmental interactions as an invasive species depends on location within the UK, posing more of a risk in southern latitudes than in the north, though there is evidence of some settlement in Scotland (Smith et al., 2014). Similarly, in Ireland, the Pacific cupped oyster, has also recruited in shallow embayments and are considered self-sustaining in some (Kochmann et al 2012; 2013). Factors considered important to influencing the recruitment of Pacific oysters in bays are intertidal extent and habitat, residence time and presence of aquaculture installations. These factors are considered when licencing such that, if a risk presents, the use of triploid oysters is advised if licencing is to proceed.

Most concern is the risk to wider biodiversity of invasive species, but it is more likely that the risk relates more to the extent of habitat transformation than to local changes in species diversity. There is little evidence in the northern areas that species of national conservation importance are being displaced, but some evidence on the southern UK shores that reef building organisms, such as *Sabellaria spinulosa* are being smothered by Pacific oysters (Herbert et al., 2016). This suggests that should warming of waters continue due to climate change there could be more significant impacts in the future.

8.4 Seaweeds

There is substantial interest at present in seaweed aquaculture in the Celtic Seas ecoregion, though at the moment this is small-scale and limited to a few farming systems and areas. An assessment by the Scottish Government (2016) indicated that coastal waters were highly suitable for harvesting and cultivating seaweed, though there were significant resources that could be harvested sustainably. The interest in seaweed cultivation is due to their ability not only to provide food, but other products from phycocolloids as food additives and for industrial application to raw materials for bioplastics (Børkan and Billing, 2022). There is also considerable interest in the abilities of seaweeds to sequester carbon dioxide (Duarte et al., 2017) and its potential for offsetting, though the mechanisms and the value of this are still under debate (Troell et al., 2022).

There is little environmental risk generally associated with seaweed farming at small scale. As far all coastal structures there will be interactions with other users of the coastal environments and there is potential for introduction of invasive species, if indigenous forms are not used. Most farming of seaweed in the Celtic Seas ecoregion is small scale and normally involves native kelp species.

As shown in some areas of China, large-scale seaweed farming, has the ability to extract large amounts of soluble nutrients from the wider environment, suggesting that expansion into larger cultivation sites may affect the carrying capacity of the environment, and may lead to facilitation of seaweed diseases, alteration of plant population genetics and wider alterations to the local physiochemical environment. A review by Campbell et al (2019) concludes that though current small-scale seaweed cultivation projects in Europe are considered ‘low risk,’ an expansion of the industry that includes ‘large-scale’ cultivation requires a more complete understanding of the scale dependent changes in order to balance environmental risks with the benefits that seaweed cultivation projects can offer

Case study 1 – Dorset and East Devon FLAG Aquaculture mapping tool

The purpose of this tool was to help identifying and mapping areas best suited (and with least conflict) to specific types of marine aquaculture, within the boundaries of the Dorset and East Devon FLAG area in England. Environmental variables (e.g. temperature, salinity, nutrients, oxygen concentration), underpinning aquaculture suitability for different species of seaweed, shellfish and finfish, were classified in optimal, suboptimal and unsuitable ranges for growth of each species investigated. Environmental layers were based on data from satellite remote sensing, in situ measurements and hydrodynamic computer modelling (e.g. to understand the long sea outfall on microbial water quality for bivalve shellfish). The suitability layers were then combined with exclusion and buffer zones (i.e. due to presence of other conflicting human activities or hard constraints such as historic sites, obstructions, transportation, water quality) using a GIS approach. Stakeholder consultation workshops were undertaken at three different locations along the Dorset and East Devon coast to review the draft maps of areas with potential for aquaculture development, and the feedback from these events was incorporated in the final maps (see below from Kershaw et al. 2021). The project produced downloadable GIS shapefiles of suitable areas for aquaculture as well as an interactive mapping tool resource available at https://www.dorsetaquaculture.co.uk/opportunities/new/map/

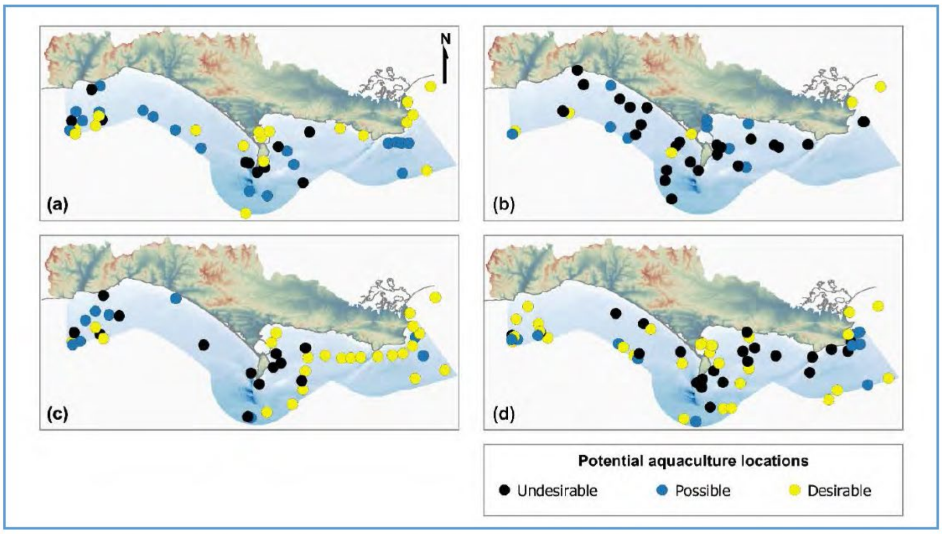


Figure 17: Maps of the desirability of aquaculture within in the FLAG region. (a) Seaweed aquaculture; (b) Finfish aquaculture; (c) Lobster aquaculture; (d) Bivalve aquaculture. Points have been georeferenced from the locations indicated by participants in the 3 consultation meetings.

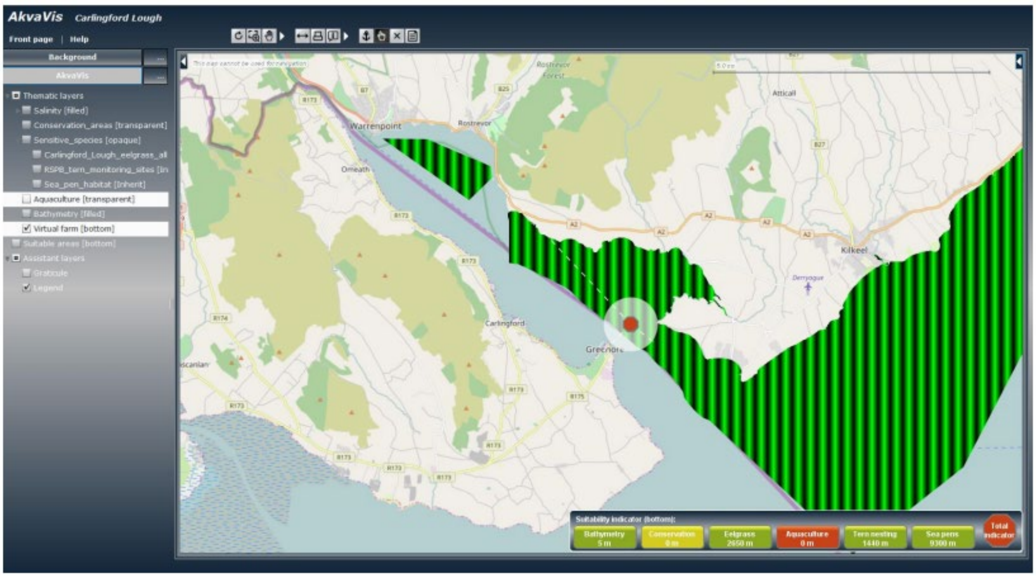
The model and mapping combine both the traditional approach where areas of least conflict are identified (environmental suitability layers combined with 'exclusion' areas), as well as preliminary elements of an ecosystem approach and integrated coastal management. Stakeholder engagements helped determining social acceptability of activities and highlighted stakeholder concerns. However no strictly economic information was included in the tool (although the 'exclusion' layers, capturing other uses of the coastal area could be considered representative of socio-economic information).

Case study 2 – AkvaVis Demonstrator applied to Carlingford Lough

The tool was developed as part of the EU project Ecosystem Approach to making Space for Aquaculture (AQUASPACE, 2015-2018). The aim was to provide a means for stakeholders (e.g. government bodies, aquaculture industry) to quickly and easily determine if an area was suitable for aquaculture development (Gangnery et al. 2021). AkvaVis uses GIS maps and thematic layers with the addition of an interactive function where choices relating to spatial parameters can be made by the user. The tool performs suitability analysis on proposed aquaculture sites utilizing a series of indicators and can create virtual farm which interacts with models and environmental data. Results are displayed as traffic light colours (i.e. green is suitable) according to the given thresholds set for the parameters. Advantage of the tool is that it is web-based and user friendly; multiple layers can be integrated in the tool.

The tool was applied to Carlingford Lough (Northern Ireland), where blue mussels and Pacific oysters are farmed. The Lough is a trans-boundary water body (between Northern Ireland and Ireland) and has a range of regulatory and management issues which are further complicated by the multiple users of the Lough (e.g. aquaculture and conservation). The environmental layers considered included bathymetry and shoreline, as well as location of sewage treatment works, existing aquaculture sites and protected areas. The tool can integrate other data such as salinity, current speed, water chemistry and socio-economic information such as dredge disposal sites, location of anchorages, marine traffic etc. (Gangnery et al. 2021).

Stakeholders were involved through adaptation and implementation of the tool to allow the determination of the key issues regarding aquaculture growth and produce recommendations on how to manage aquaculture more effectively. The final demonstrator model for Carlingford Lough was presented at a meeting of local government stakeholders, including those responsible for aquaculture licensing and for designating sites of nature conservation importance (Gangnery et al. 2021).



Example of screen display for AkvaVis with the addition of a new farm indicated by the red circle.

Case study 3 – Areas of aquaculture potential in English waters (MMO1184)

To address some of the barriers for increasing sustainable aquaculture development in England, the Marine Management Organization (MMO) undertook development of spatial models to delineate potential for aquaculture development. The approach initially focused on identifying areas suitable for cultivation of different species of seaweed, shellfish and finfish in coastal and offshore waters based on environmental variables (e.g. temperature, salinity, light availability), optimal growth ranges for the species and culture techniques (MMO 2019). 'Technical' constraints were then added (current, wave height, bathymentry etc.) considering the ability of different culture techniques to withstand environmental conditions.

A third component of the model was then added which considered other uses of the marine area or 'planning' constraints (comparable to socio-economic layers adopted in other case studies) divided in soft (reduce suitability of a particular location to aquaculture) and hard constraints (exclude aquaculture completely from an area; see figure below). The planning constraints were weighted following a hierarchical approach (see MMO 2020 for details).

The modelling was conducted in ArcGIS and Pyton, and the final layers were generated by combining the suitability layers from the three components (biological, technical and planning); the strategic areas identified are available in full in Explore Marine Plans (https://www.gov.uk/guidance/explore-marine-plans).

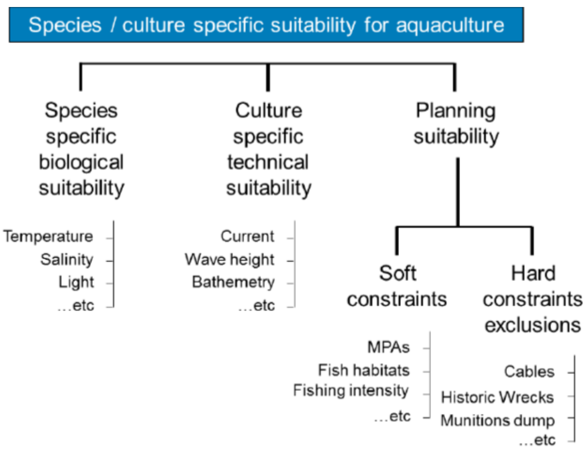
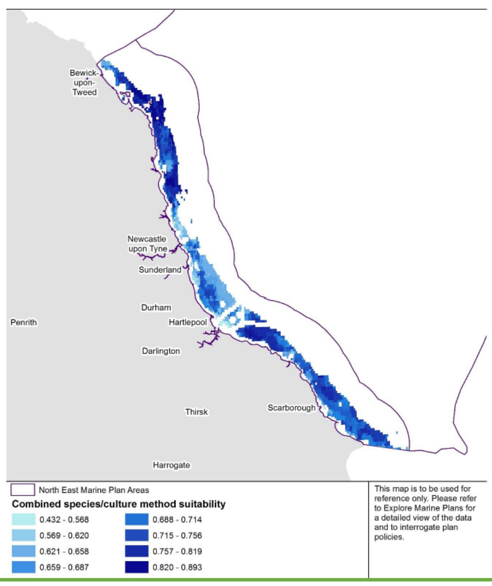


Figure 3: Atlantic cod (*Gadus morhua*) sea cage aquaculture suitability in the north east inshore and offshore marine plan areas



Overview of process adopted for determining aquaculture potential in English waters (left); example of output of the modelling process (MMO 2020).

This approach included multiple environmental and socio-economic elements and had the additional benefit of considering both inshore and offshore English waters. However, the downside of working on such large spatial coverage and with a resolution of 0.01 degree was that it would be inappropriate to apply these model outputs at the site level assessments. Furthermore, the resolution of the data varied based on different datasets adopted (in situ measurements, satellite remote sensing, model interpolations) and there was a loss of precision when data were aggregated.

Only internal (e.g. MMO, Cefas) stakeholders were involved in developing these maps and the outputs did not underwent wider public engagement (MMO 2020).

A similar approach (although simplified and with a reduced number of constraints considered) has also been adopted to determine areas of potential production of seaweed and mollusc bivalve in Scottish waters (ABPmer and Maritek UK 2021).

Case study 4 – Co-ordinated Local Aquaculture Management Systems (CLAMS) process

The Co-ordinated Local Aquaculture Management Systems (CLAMS), established by BIM is a nationwide initiative to manage the development of aquaculture in bays and inshore waters throughout Ireland at a local level. Although CLAMS is not a planning tool (based on models or GIS) as seen in the other case studies, it is still highly relevant as in each case where the CLAMS process is applied, a plan is established that fully integrates aquaculture interests with relevant national policies, the interests of other groups, Single Bay Management practices, Integrated Coastal Zone Management (ICZM) plans, and County Development plans. CLAMS is a communication network for stakeholders in bays and inshore waters to engage about common issues therefore allowing a unify approach towards issues. It is a way for the industry to interact with each other, exchanging information; however, the fact it is industry-led can present strength as well as limitations.

The process is adopted at multiple sites across the island of Ireland (see picture below from The Rising Tide report[35]).

A couple of examples of the application of CLAMS are presented below:

1. Special Unified Marking Schemes (SUMS): it allowed aquaculture operators to mark out boundaries of their licences sites in accordance with the requirements of their aquaculture licence in a unified scheme (https://bim.ie/aquaculture/advisory-services/special-unified-marking-schemes-sums/), resulting in improved navigation and safety for all users. Oyster farmers in Dungarvan Harbour (Ireland) had their own marking indicating the site but these numerous markings made navigation of the harbour difficult. The unification under a common marking scheme improved the navigation and provided efficiencies for the farmers. The project required collaboration between BIM, the Commissioner of Irish Lights, the Marine Survey Office, relevant government departments and the local farmers.

2. Ardgroom Bay Project: in this project, BIM, the Ardgroom CLAMS group, and local farmers collaborated with the dual aim to increase mussel growth in Ardgroom Bay (County Cork) and to reduce the visual impact of mussel farms (https://bim.ie/aquaculture/advisory-services/ardgroom-bay-project/). The CLAMS group negotiated an agreement between producers to reduce the stocking in the Bay to improve growth; in fact, the mussels went from taking 20 months to grow to market size to 12 months. The visual impact was improved by uniformly arranging the lines and by using grey barrels.

[35] bim_146THE,RISING,TIDE,-,A,Review,of,the,Bottom,Grown,(BG),Mussel,Sector,on,the,Island,of,Ireland.pdf

8.5 Limitations of aquaculture planning approaches

All the approaches previously presented for marine spatial planning present some limitations which are often common between the different methods and models. Data access is key for creating baseline conditions for models as well as to train and validate model performance. Particularly when working at larger scale (e.g. country), observations may not be available consistently spatially and/or temporally throughout the area considered; data may present different resolution and may be generated by different platforms (e.g. satellite, vessels), as seen in Case study 3, which may result in loss of precision and simplifications when aggregated.

Other limitations could be the analysis tools and functions adopted in the model and their replicability at other locations, as well as implementation and maintenance of the tool, particularly when web based (Gangnery et al. 2021). Knowledge gaps around interactions between farms and the surrounding environment or other activities (particularly for emerging forms of aquaculture such as seaweed) can also add uncertainty particularly in relation to the functions adopted in some of these models.

Aquaculture development often focuses on technical and biological challenges and less on socio-economic drivers, therefore socio-economic impacts of aquaculture activities are often poorly understood (Krause et al. 2015). In fact, when considering the various models and approaches, socio-economic factors are often included as 'constraints' and other activities (e.g. location of pipeline/cables, offshore renewables, fishing grounds, dredging sites, wrecks, major navigation routes, protected areas, sewage outflows). However relevant socio-economic indicators such as income of households, participation of women (Little et al. 2013), health, insurance (Krause et al. 2015), aquaculture products consumption/price, employment rate, productivity ratio etc. (Krause et al. 2019) were not included in any of the case studies considered (mainly due to lack of this type of data) and are generally not included in the models discussed in section 8.3.

Another important potential limitation is lack of stakeholder's engagement. For example, for case study 1 limited stakeholder's engagement was mainly due to lack of participation from the fishers as the workshops occurred during good weather windows and the fishers were at sea fishing. Stakeholder engagement is key; however, attention should be given to who is encouraged to participate in the discussion process, in what ways and for what reasons (Ross et al. 2013; Krause et al. 2015). Lack of engagement with key stakeholders, as well as the other potential limitations mentioned above, can ultimately result in delays (or rejections) of applications for marine aquaculture licences.

9 Future projections and emerging threats and opportunities

9.1 Legislative drivers – Brexit, marine plans and recent consultations

Legislative drivers are fundamental when making projections for aquaculture. For all nations in the Celtic Seas ecoregion, these have been driven by EU regulations, although their interpretation and implementation vary between administrations. Following the departure of the UK from the EU in 2020 legislation may diverge, within the constraints of the Trade and Cooperation Agreement (TCA, document 22021A0430(01), commonly referred to as the BREXIT agreement). At the time of writing adoption and interpretation of the TCA is still a work in progress. Further uncertainty with regard to adoption arises from the UK government's proposed Northern Ireland Protocol Act 2022 (NIP), which proposes unilateral changes to the Northern Ireland Protocol that may have knock on effects on fisheries and aquaculture for both the UK and Ireland beyond legislation directly related to the NIP. Thus, projections for aquaculture in the ecoregion have a degree of uncertainty. The initial impact of the TCA has been estimated at a > 1% reduction in production for both the UK and for Ireland, together with a >1% reduction in exports for the UK (Bartelings and Smeets Kristkover 2022). Whether or not current difficulties in cross border trading can be considered teething problems or long-term impacts remains to be seen (Churchill 2022).

The national marine plans of all Celtic Seas nations support the development of sustainable aquaculture. In England there are 11 regional marine plans areas, both inshore and offshore, developed by the Marine Management Organisations, each supportive of sustainable expansion of aquaculture in existing and potential sites. The MMO Marine Information System (MMO 2022), a spatial planning tool, presents areas suitable for future aquaculture development, including existing and potential species and different production techniques, both inshore and offshore, with a significant proportion of English seas identified as having potential for future aquaculture. Whilst quantified production targets are not easily identifiable in all marine plans, England's Seafood 2040 strategy provides an exception, specifying a target of a 10-fold increase in aquaculture production by 2040 (Huntingdon and Cappell 2020). The Welsh National Marine plan undertakes to facilitate the development of sustainable aquaculture without giving production targets (Welsh Government 2019), the associated marine planning portal provides similar layers to the MMO Marine Information System, including existing and new species and technologies, again over a large area, both inshore and offshore (Welsh Government 2015, 2022). Ireland's National Marine Spatial plan provides an outline of government policy as it relates to development and conservation in the Marine and includes aquaculture as a sector. Chapter 9 of the plan describes the objectives and policies related to Aquaculture, being supportive of aquaculture with future licencing having to consider the implications of the plan and specifically, any zonation that might apply within the MSP (Government of Ireland 2021). Ireland's Marine atlas (https://atlas.marine.ie) does not identify zones for potential development of the aquaculture sector but provides information on zonation for other sectors that is of relevance. Scotland has the largest aquaculture sector of the Celtic Seas nations, and Scotland's National Marine Plan continues to support the development of aquaculture (Scottish Government 2015). Marine Scotland (2022) provides guidance on the location of fish farms via spatial data resources. The Marine Plan for Northern Ireland includes a presumption in favour of aquaculture (DAERA 2018).

Current or recent consultations that could influence future aquaculture activities include the UK marine strategy consultation (DEFRA 2021), Ireland's Marine National Planning Framework – Consultation Report (Government of Ireland 2021) and in Scotland the Griggs report (Griggs 2022) and the resulting Scottish Aquaculture Council. The Welsh Government (2022) Sectoral Locational Guidance for Aquaculture supports the development of the sector, aiming to guide identification of future opportunities and overtime will feed into marine planning.

In summary, although Brexit has resulted in uncertainty regarding the future development of marine aquaculture, national governments are supportive of sustainable aquaculture, provided it operates within legislative frameworks including those regarding ecosystem interactions (CH6), social and economic contexts (CH7) as set out in marine plans. Recent or current consultations are likely to change some elements of the legislative framework, and that is likely to result in changed or additional requirements in the application process, however policy support for aquaculture will continue. All national plans lay the ground for bottom–up development of aquaculture operations by companies and entrepreneurs, for example England's Seafood 2040 strategy (Huntingdon and Cappell 2020) states an aim to support "companies' aspirations".

9.2 Application processes and future development

Guidance for the current processes is also available in Scotland. However, Griggs (2022) found that the majority of those involved believed that the process is not fit for purpose with a problem of mistrust between industry, stakeholders and government. The Scottish Aquaculture Council, a recommendation of the Griggs report, held its inaugural meeting in June 2022 with the aim of delivering a new framework within twelve months. A Norwegian style regulatory framework is proposed in the Scottish National Party Manifesto.

In other nations the application process is clear, with guidelines describing the process to be followed. In Wales, in April 2022, the Menai Strait Fishery Order, the main aquaculture site in Wales was renewed without a gap between the new and the old order, but it is important to acknowledge that the process can be protracted for applications for new orders, with stakeholder consultation and evidence gathering for EIAs or HRAs having resulting in the process taking several years in some cases, particularly when the Pacific oyster is the proposed culture species. The Welsh Government have not taken a position on this species at the time of writing, though the Shellfish Centre has recently reported to the WG on this matter (Smyth et al. 2022). In England's DEFRA's position on farming Pacific oysters is a work in progress, the Fish Health Inspectorate have refused an application for a Pacific oyster farm in an area where there were no established populations of Pacific oysters in the wild following advice from Defra and Natural England. (FHI Quarterly Report - 1 October to 31 December 2018).

9.2.1 Development trends

In the UK aquaculture is dominated by Atlantic salmon farming in Scotland, operated by a few large companies, whereas in England, Wales and Northern Ireland marine production is mainly of Shellfish and involves mainly small enterprises. The current picture for the sector in the UK overall is positive, although the picture is disproportionally influenced by Salmonids (Weaver et al. 2020). Ireland produces mainly salmon, mussels and oysters, with a growth of 3% volume and no increase in value between 2008 and 2018. (OECD 2021). EU-wide the production of mussels is declining (Avdelas et al 2021) and this is also the case in the UK and Ireland with a 61% decrease in the UK in the decade to 2016 (although increasing in Scotland) and in Ireland rope production was quite constant whilst bottom cultured mussels underwent a significant decline. A quick win would be that production levels of existing sectors are supported or expanded, with technologies developed and refined, although diversification of species provides some protection to the industry from climate change (Climate Adapt 2022). Research priorities to support culture of existing species include markets, diet improvements, genetics, regulation, production technology and climate change and sustainability (Slater et al. 2018).

For aquaculture to expand, or in the case of the shellfish sector, at least maintain production levels, having a social licence to operate is an important factor. Public acceptance is improving as more people have grown up with aquaculture. In the shellfish sectors, cultural and historic drivers, which in many cases have been forgotten, could improve social acceptance. A more positive view of the sector by regulatory bodies would likely follow an improved social licence to operate. (Black and Hughes 2017, Hayden-Hughes et al. submitted).

Future trends in aquaculture development are likely to be driven by the sector, with R&D input and within the government policy framework and regulatory processes outlined above. For novel species or production methods however, the application process may present an obstacle, as procedures may not be standardised, furthermore evidence required for an EIA or an HRA as required by the Habitats directive and Birds Directive (Capuzzo 2022) may be lacking until the R&D sector can provide necessary evidence. The resultant uncertainties for timeframe or even success of an application can act as a deterrent for innovation. A switch from use of the precautionary principle to adaptive management is argued to be a positive step in overcoming this uncertainty (Griggs 2022).

Current innovations in finfish diversification include land-based production of halibut in Scotland, and cleaner fish in Wales (https://www.gighahalibut.co.uk/ MOWI, 2021). A number of novel finfish species have been attempted in the UK and Ireland that have proven unsuccessful, including Sea Bass, Turbot, Cod and Barramundi (Huntingdon and Cappell 2020). Failure with these species has often been for economic reasons rather than feasibility, experience gained through these early innovations may inform future attempts at faming these species when the economic environment is more suitable for farming them. Diversification in other ICES areas may act as a template for the UK and Ireland, for example cod as a candidate species is once again being developed in Norway (Norcod 2022).

Algae has significant production globally, with 36m tons produced in 2020 (FAO 2022). This sector is in the early stages of development in the ecoregion, with all nations having research farms and there are a number of small-scale farms in operation, primarily producing kelp species. Species farmed in the CS area, whose production techniques are well developed include *Saccharina latissimi, Alaria esculenta, Laminaria digitata*, with several other species being farmed that have a lower technological readiness level, with R&D required (Wilding et al. 2021). Current farming operations are principally pilot or micro-enterprise scale (Marine Scotland 2022, BIM 2020). In the UK ten percent of seaweed is now produced via aquaculture (Capuzzo 2022), the remainder being wild harvested. A concern to be addressed for harvesting companies, that would also apply to aquaculture operations, is developing market demand and value, with product development and development of biorefineries proposed. Provided the market can be developed, there is potential for large-scale aquaculture production including development of offshore sites.

The European or native oyster has been historically overfished and impacted by disease (Hayden-Hughes et al. in press), as a result restoration effort are gaining momentum (NORA ref). Whilst funding has been secured for pure restoration projects, a model for longer term funding may be combining restoration with commercial activity, as this species as well as being of conservation concern (Laing et al. 2005). Location of commercial activities in areas that are hydrographically source areas could increase oysters in neighbouring sink areas, commercial management of regulated shellfish beds also offers protection against unregulated hand gathering, which largely reversed recovery of this species in Strangford Lough (Smyth et al. 2009).

Offshore aquaculture is a technological diversification driven by competition for coastal space. What constitutes 'offshore' in offshore aquaculture is poorly defined (Froehlich et al. 2017), with several parameters having been used in different combinations to differentiate offshore from inshore, with some aquaculture sites described as offshore that are as close as 0.3 nm from shore and with depths as shallow as 11 m. Upton (2019) defines the offshore aquaculture as operations beyond significant coastal influence (which infers different civil engineering and logistical requirements to inshore operations). Changes in legislative frameworks with distance offshore therefore do not necessarily correlate with the 'offshore' of offshore aquaculture, regulations governing licencing processes may vary depending on proposed site.

Ireland was an early participant in offshore aquaculture development, including being a key player in the Offshore Aquaculture Technology Platform that set out key factors that needed to be addressed for a move offshore (OATP 2011). Offshore finfish farming is at the late stage of technology readiness in Norway with one farm 100 m across and 40 m deep having undergone trials and currently undergoing improvements based on experiences gained, Scottish Sea Farms plan an offshore farm in Scottish waters once the Norwegian example has been proven in the next stage of trials (Evans 2020). Other companies are working on offshore designs for salmon farms, stating that moving offshore has several advantages for salmon production, reducing sea lice, improving health of fish, increasing potential space and reducing competition with other stakeholders, and having greater public acceptance (Black and Hughes 2017, www.atlantis farming.no, Soltveit 2021, Salmar Aker Ocean 2022, EATIP 2021). Commercial offshore shellfish farming is underway in England, up to 15 m from the coast (Offshore Shellfish 2022), having a high level of technological readiness that could be scaled up.

Multi-use of offshore space combining aquaculture and wind farms has been trialled in the North Sea and considered in the Irish Sea (Buck et al. 2004, Syvret et al. 2013). Currently there is no obligation for the renewable sector to collocate with aquaculture operations in the Celtic Seas, unlike in other European countries.

Integrated multi-trophic aquaculture is the culture of species from different trophic levels, including extractive species that utilise nutrients and particulates from fed species. This aims to minimise environmental impact, increase income and promote a circular economy business model (IMPAQT 2022). Pilot studies have been carried out in several locations the Celtic Seas ecoregion, including Bantry Bay, Ireland, Ardtoe and Loch Fyne, both in Scotland (Hughes et al. 2016). Beyond the CS area there have been pilots for offshore IMTA, as well as co-location. IMTA has been found to be more socially acceptable (Barrington et al. 2009, 2010).

9.3 Climate change and ocean acidification

The potential impacts of climate change on aquaculture in the Celtic Seas ecoregion are reviewed by Callaway et al. (2013) and Collins et al (2020). The Marine Climate Change Impacts Partnership report, The impacts of climate change on aquaculture (Collins et al. 2020) is a wide-ranging document, considering evidence of future changes in suitability of sites for aquaculture, carrying capacity, environmental impact, disease, invasive species harmful algal blooms and food safety. What follows is a brief summary of the MCCIP report, based on predictions of hotter drier summers, milder winters, changes in frequency and intensity of storm events and ocean acidification.

Increased precipitation and storm events may result in higher sediment loading which may result in gill damage in finfish, with increasing intensity of storms increasing the chance of fish escapes. Increased temperatures will change growth rate (positive or negative depending on the amount of increase relative to optimal temperatures for a species) and may affect tissue quality. The risk of mortalities from marine heat waves may increase. Higher temperatures may reduce the ability of benthic fauna to cope with organic fish wastes and lower salinities due to increased coastal run-off could allow faecal waste to sink more rapidly, thus siting of fish farms may need to be in waters that have a higher minimum flushing rate than at present.

Sea lice benefit from warming waters, but current efforts at mitigation may counter this (cleaner fish and subsurface cages in offshore systems). The occurrence of Amoebic Gill Disease, *Paramoeba perurans*, may increase as temperatures warm and as winter sea temperatures become milder with further risks of gill damage should harmful algal blooms and jellyfish blooms occur more frequently, although it is not clear whether either will happen.

Pathogen dynamics change with temperature, although this varies between organisms, so it is difficult to predict the outcome. A higher metabolic rate in host organisms may result in higher viral replication, on the other hand virulence may be reduced as temperatures increase, also host responses to pathogens may improve at higher temperatures. Collins et al. (2020) conclude that, whilst factors influencing pathogens are complex, increasing sea temperatures will generally increase the chance of pathogens causing pathological effects.

As temperatures increase, spatfall of *Mytilus edulis* may reduce in the southern extent of its range and increased seasonal stratification may change the distribution of larvae once spawned. The range of *M. galloprovincialis* is extending northwards, with hybridisation with *M. edulis* where ranges overlap, farming may not be impacted by reduced *M. edulis* spatfall as *M. galloprovincialis* may replace natural sources. The non-native Pacific oyster, already established as wild populations in warmer areas to the south, may expand its established range northwards.

Whilst overall confidence levels (derived from a combination of strength of evidence and level of consensus) are described as 'low' by Collins et al. (2020) for the impacts of climate change on the above, the authors argue that there is increasing argument for a 'medium' status as more evidence is gathered to reduce uncertainty. Developing production technology and methods, and the potential for offshore aquaculture make forecasting the impact of climate change more difficult, with further complexity derived from potential synergies. The top three emerging issues requiring further research were identified as the impact of climate change and ocean acidification on offshore aquaculture, interactions and fluctuations of climate change and ocean acidification on growth and survival, and capacity of different species to adapt.

Table 9.1 Below is drawn from Black and Hughes (2017) based on Collins et al 2020 and Callaway et al. 2012 and summarises potential climate effects on the different sectors.

Table 9.1. The potential effects of different aspects of climate change on different species and production (Black and Hughes 2017)

Species	Temperature	Ocean Acidification	Extreme Weather	Disease and HABs
Finfish	Minor	Minor	Significant	Significant
Mussels	Minor	Major	Significant	Significant
Oysters	Minor (positive)	Major	Significant	Significant

9.4 Disease

It is hard to forecast emergence of diseases, including zoonotic diseases, except by considering the current situation and trends (outlined in Collins, 2020). Mitigative innovations may ameliorate impacts, for example, sea lice infestations are reduced through the use of cleaner fish such as wrasse and lumpfish, developments in this technique including changes due to legislation related to the welfare of cleaner fish and the supply of cleaner fish from farmed sources, may improve the effectiveness of this method further. Also, in the case of sea lice, the drive to move offshore includes the use of subsurface cages that reduce infestations (Atlantis farming 2021).

In the case of shellfish, Celtic Seas nations, as EU member states or recent member states, have mechanisms to control listed diseases (EU Directive 2006/88) including exotic (*Bonamia exitiosa*, *Perkinsus marinus*, *Mikrocytos mackini*) and non-exotic diseases (*Martelia refringens* and *Bonamia ostreae*). Controls include designated disease area, new and emerging diseases (for example Oyster herpes microvariant OsHVμVar) can have additional controls. Gubbins (2015) considers a fourth category, that of existing diseases found in shellfish, for which biosecurity measures are also important.

9.5 SWOT analysis

The following SWOT analysis incorporates that of Avdelas et al. (2021) for mussels, with the information above.

f = finfish, s = Shellfish, o= oysters, m = mussels, sw = seaweed, a = all species.

S = Scotland, W= Wales, E=England, I = Ireland, NI = Northern Ireland, A = all nations.

Strengths	
Marine plans are supportive of aquaculture	A
History and culture	A, s, sw
Innovation, R&D	A, a
Application processes available for existing species and methodologies	A
Existing aquaculture species and methods for development or expansion	A, a
Aquaculture is included in spatial plans	S,W,E,NI
Existing markets at current scale	A
Extractive, low trophic level production	A, s, sw
Clean water	S, I, NI ??? s

Weaknesses	
Length of time taken for approval/security of tenure	W,E,???
Low govt staffing levels for application and regulatory processes.	A
Risk aversion by regulators	???

Investment, R&D, infrastructure and licence required for offshore and sea-weed farms at scale (= opportunity for big businesses)	A
Lack of inshore space / competition with stakeholders.	A???
Small companies	A???

Opportunities

Genetically produced triploid Pacific oysters	o
Licencing for mussel seed	s
Offshore production close to technological readiness	S
Diversification of species and technologies	A, a
Potential for sustainable expansion	A, a
Bottom–up development for shellfish	A, s
Top-down development for finfish and scaled up operations	A, s,sw,f
Desire for food security	A, a
Integrated multitrophic aquaculture	A, f,s,sw

Threats

Non-native aquaculture species	A
- current evaluation of Pacific oyster	A???
Mass mortality/disease	A,a
Opposition from other stakeholders	A,a
forgotten culture and history	A, s, sw
effective lobbying groups against aquaculture	A
Few hatcheries if major expansion	a
Prioritisation and staffing levels of legislative bodies	A???
- Brexit	A
water quality, disease, hatchery supplies, staff availability in government and regulatory bodies	A
Climate change	A, a
Increased incidence of HABS and jellyfish blooms	A, a

Extreme weather events	A, a
Temperature increases beyond optimal ranges	A, f, ??
Reduction in carrying capacity	A
Poor water quality	???

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Annex 1: List of participants

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Annex 2: Resolutions

WKCSAO - Workshop on the Celtic Seas Ecoregion Aquaculture Overview

2022/WK/ASG03 Workshop on the Celtic Seas ecoregion Aquaculture Overview (WKCSAO) chaired by Francis O'Beirn, Ireland*, and Henn Ojaveer*, ICES, will be established and will meet 26–29 April online 2022 to:

a) Review and discuss the data and information collected for the Celtic Seas ecoregion aquaculture overview, identify the gaps and agree next steps to complete the draft overview;

b) Collate datasets and resources for the aquaculture overview by completing the ICES Data Profiling Tool (https://www.ices.dk/data/tools/Pages/Data-profiler.aspx); and

c) Produce a workshop report detailing the conclusions of ToRs a and b. This report will serve as the foundation for the Celtic Seas aquaculture overview.

WKCSAO will report by 15 of June for the attention of the ACOM.

Supporting information

Priority	Aquaculture is a high-priority topic for ICES. ICES work on aquaculture is part of a wider portfolio of work that seeks to advance and share scientific understanding of marine ecosystems and the services they provide, and to use this knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals. The ICES Strategic Plan states: 'We will regularly publish, update, and disseminate overviews on the state of fisheries, aquaculture, and ecosystems in the ICES region, drawing as appropriate on analyses of human activities, pressures, and impacts, and incorporating social, cultural, and economic information.'
Scientific justification	The process of establishing ICES AOs was initiated in 2019, with: i) forming a core group consisting of representatives from ACOM leadership, SCICOM and Secretariat, and ii) agreeing on the directions and procedure of further work of the core group. Objectives and contents of AOs was agreed by ACOM. The process established for the first AO (Norwegian Sea) also involved arranging a workshop (WKNORAO).
Resource requirements	The lead author of the Celtic Seas ecoregion AO (Francis O'Beirn) has already established an expert team and started the work. This will serve as the main input for the meeting.
Participants	The WK will be attended by experts contributing to the Celtic Seas ecoregion AO, as wel as other interested scientists from ASG.
Secretariat facilities	Setting up webex calls.
Financial	No financial implications.
Linkages to advisory committees	Direct link to ACOM.
Linkages to other committees or groups	ASG, WGAGFA, WGECCA, WGOOA, WGPDMO, WGREIA, WGSEDA, WGSPA, WGEEL, WGSOCIAL, WGECON, SICCME, SIHD
Linkages to other organizations	DGMARE

Annex 3: Review Group Consensus Report

Messages from Review Group for ICES Workshop on the Celtic Seas Aquaculture Overview (WKCSAO) Report:

Review Group Participants:

- Dr Seth Theuerkauf (Review Group Lead), Renewable Energy Program Specialist, Office of Renewable Energy Programs, Bureau of Ocean Energy Management, U.S Department of Interior (formerly with NOAA Fisheries)
- Dr Katherine Mary Dunlop, Researcher, Benthic Resources and Processes, Institute of Marine Research, Norway.
- Dr Matthew Gubbins, Fisheries Data Programme Manager and UK Delegate to ICES Council, Marine Scotland Science

The three members of the Review Group developed separate reviews of the proceedings of the Workshop on the Celtic Seas Aquaculture Overview, and then discussed the report and their reviews virtually via Microsoft Teams on August 25th and 30th 2022. In particular, the reviewed report was to serve as the foundation for the ICES Celtic Seas Aquaculture Overview and was to address the following points:

A. Summarize regional and temporal information on aquaculture activities, practices, and production of cultured taxa;
B. Describe the relevant policy and legal foundation;
C. Consider the environmental and socio-economic interactions of aquaculture activities and practices;
D. Provide insights on the interaction of environmental, economic, and social drivers;
E. Consider future projections and emerging threats and opportunities.

The review discussion centred on an assessment of the following questions:

1. Were the Terms of Reference of the original report adequately met or addressed?

Yes, the three reviewers found that the TORs were generally well-addressed and covered by the information presented in the comprehensive report. We applaud the effort that the authors have made to compile extensive amounts of information and data across the region. However, the reviewers identified several areas where improvements should be made to the report and the Aquaculture Overview to be developed from it—these specific areas are described in the 'Consensus Report – Major Consistent Recommendations' section below.

2. Can consensus be reached with regards to the major points made within the separate reviews? Any key differences of opinion among the three reviewers? Note any major shared comments/concerns.

Yes, the three reviewers found that consensus could be reached with regards to the major points made within the separate reviews—these specific areas are described in the 'Consensus Report – Major Consistent Recommendations' section below. However, each reviewer raised different issues within each of their individual reviews that all three reviewers agreed should be addressed by the authors.

3. Is the scientific information presented in the report sound and clear? Is it a sound basis for the ADG to prepare ICES advice from? What areas represent strengths (what information is covered very well)?

While generally the scientific information presented in the report is sound and clear, there are several areas that require strengthening. We believe that, with revision, the document would be a sound basis for the ADG to prepare ICES advice from. Throughout the document there is an inconsistent level of detail—excessive detail in some cases, while not enough detail in others (see (b) in the 'Consensus Report – Major Consistent Recommendations' below). Additionally, there are areas of the document where there is inadequate referencing to supporting material, such as in the case of climate change-related issues. Further, there is a lack of reference to geographically-relevant studies—there are many references to Norwegian studies when there are appropriate studies from the Celtic Seas region available (see (d) in the 'Consensus Report – Major Consistent Recommendations' below). By way of strengths, the reviewers applaud the authors' effort to capture and incorporate data from across a broad region with multiple jurisdictions. The reviewers also appreciate the incorporation of socio-economic data and information throughout the report.

4. Where are there gaps in the presented information (particularly as they relate to A-E above)? What areas represent weaknesses (what information is not covered very well and should be strengthened)? Which (if any) should be addressed immediately, and which represent gaps that can be addressed in future iterations/updates?

Within the 'Consensus Report – Major Consistent Recommendations,' we provide an overview of the gaps that the reviewers feel should be addressed to improve the document and refer the authors to that list. Most notably, the reviewers identified an inconsistent level of detail and coverage across multiple sections—particularly as it relates to coverage for specific jurisdictions. Often one or two jurisdictions dominated coverage within a specific section. In cases where these gaps in coverage are due to lack of data or information, they should be addressed in future iterations/updates. In cases where data or information is available but was not incorporated, it should be addressed immediately. Further, while the document provides an extensive amount of information, there is a notable lack of synthesis in multiple areas—this is described further in the 'Consensus Report-Major Consistent Recommendations' (a) and within the individual reviewer reports. To the extent possible, this synthesis should be incorporated immediately.

Consensus Report – Major Consistent Recommendations:

Below, we describe the major consistent recommendations across reviewers and refer the authors to the individual review reports for more information.

a. Despite presenting a great deal of information and data, there is a notable lack of information synthesis into major observations, trends or patterns. As a specific example, in Section 2.9 – more space and time should be dedicated to description of the major gaps that were identified and opportunities for improvement. The individual reviewer reports point to specific areas of the Workshop Report where this synthesis is needed.
b. While there is much detail presented for many sections, there are notable gaps in information / inconsistent levels of detail presented across the regions described. As an example, for the section describing policy and regulatory frameworks there are discrepancies in the level of detail provided between the regions—more information could be presented for Scotland. Conversely, in some sections—such as section 2—there is extensive detail included related to aquaculture methods (e.g. oyster and mussel farming) that is not warranted, and is not consistent/balanced with the level of detail for all aquaculture methods described (e.g. salmon farming). The individual reviewer reports point to specific areas of the Workshop Report where additional information/detail is needed.

c. The authors should review the overall report with an eye for 'plain language,' recalling that the report is generally intended for a non-technical audience.
d. Multiple reviewers identified consistent structural and technical details across their reviews that need to be addressed. For example, as it relates to structural/formatting details for the report, the references for, and locations to, specific figure and table are not consistent and/or located where they are expected. As another example as it relates to technical details, the impacts of warming waters are generally described, but specific impacts to the Celtic Seas region are not and should be.
e. More region-specific references and details are needed, particularly in Section 6 – Ecosystem/Environmental Interactions. There are currently more references to Norwegian studies than those of direct relevance to the Celtic Seas ecoregion.
f. The reviewers did not see clear value in the SWOT analysis incorporated into Section 9, generally finding it poorly incorporated. Specific comments are included in the reviewer reports, but the authors should re-evaluate inclusion of the SWOT analysis. It may be better to convert the SWOT analysis into some basic, synthesized text.

Individual Reviewer Reports from the Three Reviewers:

Review by Dr Seth Theuerkauf (Review Group Lead)

Big Picture Comments:

- In a very broad sense, the Terms of Reference have been adequately addressed by the Workshop report authors with information coverage including the range of requested material by topic (A-E). However, there are areas of gaps in coverage that would benefit from strengthening. Generally, there is lots of great information and data presented—but there is not much by way of its synthesis into major observations, trends, or patterns.
- Section 2 - History (even in a general sense) of production is not presented, or at least not consistently. This section would be strengthened with a description of when various farming practices began, their history of production growth, etc. This does not need to be extensive, as Section 3 should provide the granular detail and trend data. As an example, under Section 2.6 for Wales (page 27), it is described that 'long-running efforts to get old leases replaced' are underway – what is meant by old?
- Section 2 – Information on market value of production and employment is not consistently presented – for example, the sections cantered on Ireland do not include any market data, but the sections on the UK do. The Scotland section includes data on employment, for example. Section 7 on Social and Economic Context on page 68 provides some of this information. I recommend removing this information from Section 2 and relocating it to Section 7.
- Section 2.9 – spend a little more time and space capturing the major gaps that were identified and opportunities for improvement. They may vary across the regions described, but there should be a few common threads that can be highlighted here.
- Section 3 – this is all great data, but it is difficult to sift through it all. I recommend a concluding section that summarizes key trends. This currently exists in Section 7.3, but it doesn't fit appropriately there.
- Section 5 – inconsistent level of detail. Scotland, for example, has very little specific information on aquaculture health regs.
- Section 5.2 – Inconsistent level of detail on monitoring and management for Scotland, and no info for England and Wales.
- Section 6.3 – more detail is needed for the shellfish section, especially related to genetic interactions. It is noted in multiple locations that seed are imported, have genetic interactions been studied?
- Section 9 is clear, except the SWOT analysis (what is meant by '???', what is meant by '-' in entries within the table)

General Comments:

- Passive voice is used throughout the document and should be changed to active. For example, on page 2, paragraph 2 at the end of the sentence: "When considering access to culture sites, it would be important that appropriate shore-based (i.e. terrestrial) facilities are appropriately located."
- Check Figure references throughout. Some are missing in Section 2, and others don't map appropriately.

Specific Comments:

- Page 5, Section 1.2 – Is aquaculture allowed in conservation areas? It is never explicitly stated in this section, but it does get clarified on page 74. I recommend a short note clarifying that aquaculture is not *a priori* excluded in protected areas.

- Page 6, Section 1.3 – What is the eutrophic status of the Celtic Seas? Are there nutrient concerns? For example, in Section 2.4.3, it is introduced that declining water quality is affecting farm sites. A general overview early on would help. It is further stated on page 75 in section 8 that eutrophication is a concern – early indication of this is requested.
- Page 7, Section 1.4 – General concerns around increasing temperatures are presented (e.g. poleward expansion of species), but are there any specific examples or concerns that have been documented for the Celtic Seas? This comment similarly applies to elsewhere in the Celtic Seas (e.g. Northern Ireland). This gets somewhat addressed later in the text under Section 8.3 on page 76 in the last paragraph, but an earlier description would be useful.
- Page 10, Section 2.2 – Move forward the maps of farming areas – they are currently at the ends of the sections, but make the most sense to be near the content where they are described. They also should be referenced as Figures. Consider using 'inset' maps that allow for zoomed-in views of areas. It is currently difficult to see the dots (I printed in black and white). The map in the Scotland section (Figure 2.7) is a good example.
- Page 10, Section 2.2 – check capitalization of words in last paragraph.
- Page 11, Section 2.2.1 – graphics or visualizations of the various farming methods/gears would be useful. Figure 2.1 is a good example of a useful graphic—consider using a panel of multiple images if excessive graphics is a concern.
- Page 11, Section 2.2.1 – what is the ploidy of farmed shellfish? Typically, diploid? Any genetic concerns with sourcing?
- Page 14, Section 2.2.4 – Why is production of Atlantic Salmon currently limited to only 25 of 67 sites?
    - Note this statement is inconsistent with what is stated in section 7.3 (page 70): "Most if not all suitable sites for this segment, using current available techniques, are either already licensed or otherwise used."
- Page 15, Section 2.2.6 – move the oyster content to the preceding shellfish section.
- Page 20, Section 2.4.1, Paragraph 2 – avoid use of 'us' in the last sentence on this page—reword.
- Page 30, Table 2.4 – consider including this table as an Appendix as it is otherwise an inconsistent level of detail (too much information) as compared to other sections.
- Page 49, Section 4.1.1 – the first full sentence does not make sense – 'which are defined as extensive fish farming operations' – the rest of the sentence is referring to shellfish/seaweed farming? Please clarify.
- Page 50, Section 4.1.2 – 'confirmation of ownership or lease of the site' – who owns the seabed? Can it be privately owned, or is it leased by the gov't?
- Page 52, Section 4.1.5 and Page 52, Section 4.1.6 – the bullet format is not consistent with the other sections and does not improve clarity. Please shape into sentences/ a paragraph or two.
- Page 54 – incomplete table without a caption.
- Page 60, Section 6.2.1 – are there concerns about nutrient enrichment/eutrophication at the waterbody scale?
- Page 71 – remove "!" in second paragraph, and remove/reword the phrase 'guilty by association.'
- The format of Section 8 needs improvement. 8.3 provides detail on planning approaches, beginning on page 75, followed by a section focus on Seaweeds in 8.4, then a series of Case Studies, and section 8.5 which provides an overview of aquaculture planning approaches. Re-think the structure here to improve flow. Section 8.5 likely does not need to be its own section, it can be rolled into 8.3. The Case Studies could be better integrated into 8.3.

Review by Dr Katherine Mary Dunlop

Note - please also see the attached, annotated document of the Workshop Report which includes tracked changes edits. Many of the edits captured below are captured in the annotated document, including some additional minor grammar/punctuation issues.*

General Comments:

In general, the report offers a well-written and thorough review of aquaculture activities in the Celtic Sea region that meet the TORs. It was well structured, easy and interesting to read. The figures and tables are in general presented well, however, some of the in-text references to figures are incorrect and I recommend that the authors consider the position of the figures and tables in relation to where they are first mentioned. For example, Figure 6.5 is referred to in the text but is not present in the document. A table presented on page 56 is not labelled or referred to in the text.

Chapter 1 begins by addressing the oceanographic conditions of the region. For the oceanography section I would suggest the addition of further linking information to show why it is relevant to aquaculture in the region, such as is done in the temperature section (1.4).

Within chapter 2, there are several sections that I would question whether they warrant the level of detail provided. For example; a high level of detail has gone into describing the methods related to oyster and mussel aquaculture, down to the diameters of the ropes and weight of concrete blocks. This is not a level of detail repeated for salmon aquaculture. Secondly, quite some details are used to described manila clam culturing however at the end it states that there are "no operators producing Manila clams in Ireland". I therefore question if the culture of this species merits several paragraphs if it is currently not farmed. Perhaps it could be stated first that they are not currently produced but were recently. This could be followed by a brief summary of what methods have been used. Finally, a high level of detail is used to describe 2 individual farms sites in Northern Ireland – down to the state of the seabed at those 2 individual sites. This seems an unbalanced level of detail and could be reduced. Minor edits to the text are suggested, mainly for chapter 2 (see specific comments below).

In chapter 5, the monitoring and management section (5.2) does not contain information on Wales and England. In chapter 6, information on nutrient enrichment is based on Norwegian studies (Vestlandet and Trondelag). While I agree with the authors that can be relevant to Scotland, there does exists a body of literature from Scottish researchers that I would think can be more appropriate to use here. For example, work by Thomas Wilding, Kenneth Black, Lois Nickell and Thomas Nickell among others.

In chapter 8, I was unclear of the connection of the information presented on pages 77 & 78 to the case studies. Perhaps the role of this information is to provide an introduction. If so this could be linked better in the text. Finally, in Chapter 9, I found the SWOT analysis at the end poorly incorporated with the rest of the document. Further supporting information could be provided here to link it better within the context of chapter 9.

Specific Comments:

Some unnecessary repetition of words and I have suggested ways that the text can be more concise.

- 1.2. page 5. And national legislation there **are** many mechanisms…
- 1.2 page 5. Not include those areas designated for birds which should **be** considered
- 1.3 page 6. This is generally **in a** poleward **direction** in winter and spring **but** can **be reversed** in summer
- 1.4 page 7. Use acronym SST as stated in the previous line.

- 1.4. page 7. Problems may present **themselves**
- 1.4. page 7. Are the effects of temperature changes, such as algal blooms and jellyfish, specific to the Celtic Sea region? Better if this could be more specific.
- 2.1. Introduction. First line. I have recommended some rearranging of the text. "In this chapter we have defined marine aquaculture **as** the cultivation of finfish, shellfish and seaweed that will usually require a producer/ grower on-growing the species of choice on a licensed marine aquaculture/mariculture site. Marine related aquaculture activities **that** include fisheries…"
- 2.1. Introduction. "Native oyster (*Ostrea edulis*) fisheries exist in all the Celtic Sea areas **and are** discussed in the subsequent sections. **Until** recently,…"
- 2.1. Introduction. "Strived" replaced with "thrived".
- 2.1. Introduction. "**However** overfishing, disease, pollution and habitat loss were responsible for a large decrease in stocks or the complete collapse of many of these fisheries."
- 2.1. Introduction. "**R**ecent restoration projects **have** focused on native oysters and there are many examples of restoration projects in the Celtic Seas ecoregion. These are not all included in this chapter but it is important to note this for future aquaculture overview**s**."
- Figure 2.1 could be moved further up to be close to where it is first referred to.
- 2.2.1. "The majority of oyster culture in Ireland is off-bottom using bags and trestles in the intertidal zone (intertidal oyster cultivation)."
- 2.2.1. "The bags or plastic 'pouches' are mesh bags that allow water to flow **through** the bags bringing food to the oysters."
- 2.2.1. "Oyster spat, supplied by hatcheries, **are** placed in the mesh bags.".
- 2.2.1. page 11. "The sedimentary habitats where intertidal oyster culture is located must be such that the trestles do not sink quickly and that access **is easy** for permitted vehicles."
- 2.2.1. page 11. "The full oyster production cycle is variable ranging from 18 to 24 months, **depending** on a number of factors including size and source of spat, environmental conditions and good site maintenance and husbandry."
- 2.2.1. page 12. Table 2.1. was quite far away from where it was first referred to.
- 2.2.1. page 12. I think that Table 1 should be Table 2.1.
- 2.2.1. page 12. "This **method** of off-bottom Pacific oyster trestle cultivation has been noted throughout the Celtic sea regions"
- 2.2.3. Page 13. Figured 2.1 referred to here but this shows Killary Harbour which is not named in the text.
- 2.2.3. Page 13. "Given the nature of the bottom culture of mussels and the reliance on the use of large dredging vessels, licenced areas tend to be larger than for other aquaculture production areas."
- 2.2.4. Page 14. Figure 2.2. refers to Shellfish locations while 2.3. shows finfish aquaculture locations.
- 2.2.4. Page 14. "Cages are **arranged** in grids which can vary in number from four to 16 cages."
- 2.2.4. Page 14. "in a sufficient number of bays and loughs that **provide** multiple options for site alternation and fallowing, to suit circumstances."
- 2.2.5. Page 14. Clarify what "main groups" means.
- 2.2.5. Page 14. "There is increasing interest also in the **cultivation of** *Laminaria digitata*"
- 2.2.5. Page 15. "In some sites, operators may rely on **the** wild settlement of seaweed and selectively harvest on the basis of **demand** from buyers."
- 2.2.5. Page 15. It is stated that seaweed aquaculture is in 4 production units while earlier it is stated that it is cultured in 14 sites. Can this difference to clarified?
- 2.2.5. Page 15. " over summer until by September they have reached 10–12 mm."

- 2.2.5. Page 16. "Suspended for now, it is hoped to recommence production there or in nearby Bantry Bay, within the coming years."
- 2.4.1. Page 20. "It allows a precautionary approach to management **to be taken** and ensures that an effective spawning stock is maintained."
- 2.4.4. Page 21. Figure 2.4 shows Pacific oyster cultivation and does not relate to the salmon farm sites as described in the text.
- 2.4.6. Page 22. "There are also a number of fishery orders for wild scallop harvesting. There are **several** wild cockle and winkle fisheries, they are not detailed here however it is worth noting that there is one licensed area to farm periwinkles in NI"
- 2.5.5. Page 26. Table 2.4. is referred to in the text before Table 2.3.
- 2.6. Page 26. "**I**nformation **describing** marine aquaculture activities around the coastline of England and Wales is frequently presented jointly, **thus** complicating the data gathering **process.** Hence England and Wales marine aquaculture…"
- 2.6. Page 26. Figures 2.6. and 2.7. do not relate to Wales aquaculture production.
- 2.6.4. Page 29. Figure 2.7 should be figure 2.10.
- 2.7. Page 32. "The main species cultivated on marine sites around the coast of England are mussels and oysters, mainly **through** bottom cultivation…".
- 2.7.3. Page 33. Confusing that Wales finfish sites are included in the England section.
- 2.7.5. Page 33. The first section does not form a proper sentence.
- 2.7.5. Page 33. "There is a native oyster hatchery in Morecambe **Bay where** stock is…"
- 2.9. Conclusion. Page 35. I think that differences in aquaculture regionally is also based on the physical conditions of the coastlines. For example, Scotland has deep sheltered fjords suitable for finfish aquaculture.
- 2.9. Page 25. Was this what is meant? "The inconsistency of the use of **the term** marine aquaculture in the different regions complicated the search for information, making data gathering difficult."
- 3.1. Page 36. Table 3.1. referred to in close succession. Consider removing one.
- 3.2. Page 38. "For both finfish and molluscs, the number of species reported annually has increased **until 2011…**" – added for clarification and to match the figure.
- 3.2. Page 38. "late 1980s, **after which** finfish have formed the bulk of production…"
- 3.3.1. Page 39 "In Northern Ireland, a single company established in 2008 produces up to 600 tpa of organically **sourced salmon…**"
- 3.3.2. Page 41. I am surprise by the sharp jump in cleaner fish production from 2019 to 2020 in Scotland. Can an explanation be provided?
- Page 56. I was unsure what this table was representing. There is no caption or reference to it in the body of the text.
- 5.1.2. Page 60. "In Ireland, the use **of** non-**chemical** treatment has increased."
- 5.2.3. Page 61. This section was lacking in details compared to the previous sections on Ireland and Northern Ireland. I am missing details on some of the monitoring programs for example sealice and benthic condition.
- 5.2. The monitoring and management section do not contain information on Wales and England.
- 6.2.1. Page 63. Information on nutrient enrichment is based on Norwegian studies (Vestlandet and Trondelag). While I agree with the authors that can be relevant to Scotland there is a body of literature from Scottish researchers that would be more appropriate to use here. For example, work by Thomas Wilding, Kenneth Black, Lois Nickell and Thomas Nickell among others.
- 6.2.2. Page 64. I think the line that the Norwegian traffic light system related to sea lice levels is under review is not necessary to include as the Norwegian system is not a focus here.

- 6.2.4. Page 67. The reference Parsons et al., 2020 is a Norwegian study of the effects of anti-lice pesticides on European lobster in Norway. Perhaps there is a Celtic Sea based reference that would be more appropriate to describe treatment methods.
- 6.2.4. Page 67. Figure 6.1. is quite far from the text where it is first mentioned.
- 6.3. Page 69. " Bivalves are grown throughout the Celtic Seas area. There are **two main** species grown,..»
- 6.3. Page 69. Figure 6.5. No reference to this figure in the text.
- 7.3. Page 73. It is stated that chapter 5 deals with environmental effects of algal blooms and jellyfish swarms though I see that these are not mentioned in chapter 5. Perhaps come more information can be included.
- 8.3. Page 77. It was unclear what the information on page 77 related to. Perhaps this is introducing the case studies. The structure here can be made clearer.
- 8.4. Page 78. Again, here it can be made clearer how this information is related to the case studies presented after.
- 9.2.1. Page 88. (NORA ref?)
- 9.2.1. Page 89. "**However currently** there is no obligation for the renewable sector to col-locate with aquaculture
- 9.5. Page 91. The inclusion of the SWOT analysis at the end seems to be poorly incorporated with the rest of the document. Little supporting information is provided.

Review by Dr Matthew Gubbins

General Comments:

Addresses ToRs reasonably well given the task and available data.

- i) A good, thorough if not very consistently presented overview of activity production and practices across the jurisdictional areas.
- ii) The policy and regulatory frameworks are well covered but there are discrepancies in the level of detail provided between the regions. In particular, more information could be presented for Scotland.
- iii) Good overview of the interactions, but leans heavily on quantified examples from Scotland giving perhaps a one-sided picture particularly for finfish aquaculture.
- iv) Future projections reasonably well addressed as far as could be predicted. The SWOT analysis at the end is perhaps not the most useful way of presenting inconsistent and uncertain information.
- v) Although addressed in part throughout, it is not clear that the gaps in information have been specifically addressed, particularly in relation to management. Critical for example is the uncertainty over impacts of pathogens on wild stocks, movements of fish and how that can be addressed by spatial management.

Some consistency issues in scope between national sections in the overview e.g. Food safety concerns for shellfish aquaculture addressed in some country sections, not others, nor at a ecoregion scale.

Authors have done a fantastic job of compiling different data sources to provide a picture of production trends across the whole ecoregion. This must have been a difficult task, but I am not sure Section 3.1 needs quite so much detail explaining the complexities of the source data.

Section 6 in particular is very regionally biased with much publicly available data from Scotland providing a fairly one-sided view of interactions from finfish culture.

Some sections are overly technical for a lay overview such as this. For example, section 6.3 and 8.3 reads as a scientific publication rather than for a lay audience.

Specific Comments:

- Executive Summary. Para 2 line 5 “policy drivers and regulatory frameworks”
- Exec Summ Para 7 line 2. Delete “and”
- Page 3 1.1 bullet 5. Figure 1.2 does not show these VMEs or features, it is an EMODNET derived substrate map.
- Page 5 section 1.2 does not touch on how these conservation areas are taken into consideration on the planning licensing and operational regulation of aquaculture in the ecoregion.
- Page 6 section 1.3 line 8. Incorrect reference. Should be Scotland’s National Marine Plan 2015
- Page 7 Fig 1.5 reference should be Baxter et al 2011 (Scotland’s Marine Atlas)
- Page 7 Section 1.4. Lacks any referencing for temperature effects. Could recommend the UK Marine Climate Change Impacts Partnership Aquaculture Report Card which reviews this extensively. Not sure what value the baseline temperature data have without any assessment?
- Page 12 2.2.2 para 3 line 4. “embayments”
- Page 15 2.2.6 para 6 “Pecten maximus” italics

- Page 15 last paragraph. Not clear whether all the culture systems and volumes described are for hatcheries, on-growing or whether all combined or just urchins total 30 tonnes? Is the paragraph describing all land-based shellfish systems in Ireland? If so make clear.
- Page 19 section 2.4 Para 1. Freshwater trout production out of scope for terms of reference.
- Page 19 2.4.1 para 2. Explain Ortac TM technology?
- Page 23 2.4.3. What is "mopping" for starfish. A locally well-known practice that needs to be explained to a general audience.
- Page 26 2.5.5 Para 1. "As an emerging sector"
- Page 26 2.5.5 Line 4 – phrase repeated
- Page 26 2.5.5. Could add the known number of Marine Licences for seaweed farms (6 at last count ca. 2019) and that the majority are experimental/research in nature (information available from the SEA/Licensing Operations Team, Marine Scotland
- Page 28 2.6.3. Section misses the significance of the sheer volume of mussels produced from this hotspot of mussel cultivation for the ecoregion. Line 3. "sites"
- Page 35 2.9 Conclusions line 3. I think this more likely reflects how the topography and site suitability for the cultured species and methods varies across the ecoregion.
- Page 48 3.7 line 2. And 1st bullet line 2. The common name for this species is "dabberlocks" not "babberlocks"
- Page 50 Section 4. Very imbalanced content on policy content between UK and Ireland
- Page 54. 4.14. lacking in detail compared to other countries. Scope of the different regulatory instruments not clear from the text. Eg Marine Licence manages navigation, discharges from vessels etc. Planning consent is permanent and applies to the location not the operator and triggers the EIA, lease is time bound. No mention of the HRA process etc. More detail available from Fish farm consents - Aquaculture - gov.scot (www.gov.scot)
- Page 58. 5.1.3. Again, Content for Scotland disproportionately light. More details available from the link Fish Health Inspectorate: authorisation and registration - gov.scot (www.gov.scot)
- Page 59 5.2.1 para 3 line 3. "Or shorebird" should be "of shorebird"?
- Page 61 5.2.3 Again Scotland relatively light on detail. No mention of the extensive Food standards monitoring programme for shellfish food safety (microbiological and biotoxin). No detail on the scope of the SEPA/CAR licence conditioned environmental monitoring. All available on the SEPA website.
- Page 63. What is the value of Fig 6.1? What point is being made and why is it only shown for part of the ecoregion? Why this subset of discharged substances?
- Page 66 6.2.4 "Therapeutants are primarily used for.."??
- Page 72 7.3 Para 5 line 9. Red tides are not appropriate terminology for the harmful algal events affecting bivalve culture in this ecoregion.
- Page 72 para 6 – Salmon is actually the UKs biggest food export, not just Scotland.
- Page 73 para 3 line 5. "Management of these factors"
- Page 76. Para 3. I remain unconvinced that the potential for co-location of these industries is a realistic prospect in this particular ecoregion given the spatial differences in site suitabilities between the sectors.
- Page 78 last para "*Sabellaria spinose*" in italics
- Page 87 9.2 Para 1 line 1 - Guidance for the current processes is also available in Scotland.
- Page 87 9.2 – Not sure what this section is trying to say or what value it adds to the overview?
- Page 91. I am not convinced the SWOT analysis as completed is particularly useful as clearly the level of analysis attempted can only be partially or uncertainly applied across the jurisdictions within the ecoregion?

Annex 4: Responses from WKCSAO to RGCSAO Report

Messages from Review Group for ICES Workshop on the Celtic Seas Aquaculture Overview (WKCSAO) Report:

<u>Review Group Participants:</u>

- Dr Seth Theuerkauf (Review Group Lead), Renewable Energy Program Specialist, Office of Renewable Energy Programs, Bureau of Ocean Energy Management, U.S Department of Interior (formerly with NOAA Fisheries)
- Dr Katherine Mary Dunlop, Researcher, Benthic Resources and Processes, Institute of Marine Research, Norway.
- Dr Matthew Gubbins, Fisheries Data Programme Manager and UK Delegate to ICES Council, Marine Scotland Science

Consensus Report – Major Consistent Recommendations:

Below, we describe the major consistent recommendations across reviewers and refer the authors to the individual review reports for more information.

Despite presenting a great deal of information and data, there is a notable lack of information synthesis into major observations, trends or patterns. As a specific example, in Section 2.9 – more space and time should be dedicated to description of the major gaps that were identified and opportunities for improvement. The individual reviewer reports point to specific areas of the Workshop Report where this synthesis is needed.

Response: It is acknowledged that trends are not discussed in great detail in any one section. This was limited by time and availability of relevant expertise within the group.

While there is much detail presented for many sections, there are notable gaps in information / inconsistent levels of detail presented across the regions described. As an example, for the section describing policy and regulatory frameworks there are discrepancies in the level of detail provided between the regions—more information could be presented for Scotland. Conversely, in some sections—such as section 2—there is extensive detail included related to aquaculture methods (e.g. oyster and mussel farming) that is not warranted, and is not consistent/balanced with the level of detail for all aquaculture methods described (e.g. salmon farming). The individual reviewer reports point to specific areas of the Workshop Report where additional information/detail is needed.

Response: Unfortunately given the overview covers 5 jurisdictions, there is considerable degree of inconsistency in how production information is reported and subsequently recorded. The lack of detail on the production methods used in later examples is noted and was purposely done to avoid repetition. This was in subsequent sections, communicated by referring to previous section where more granular detail was provided.

The authors should review the overall report with an eye for ‘plain language,’ recalling that the report is generally intended for a non-technical audience.

Response: Addressed in ADG report.

Multiple reviewers identified consistent structural and technical details across their reviews that need to be addressed. For example, as it relates to structural/formatting details for the report, the references for, and locations to, specific figure and table are not consistent and/or located where they are expected. As another example as it relates to technical details, the impacts of warming waters are generally described, but specific impacts to the Celtic Seas region are not and should be.

Response: Addressed.

More region-specific references and details are needed, particularly in Section 6 – Ecosystem/Environmental Interactions. There are currently more references to Norwegian studies than those of direct relevance to the Celtic Seas ecoregion.

Response: This comment is noted was rectified in the subsequent Advice Drafting group report where more Celtic Seas centric references were identified and used. These and any new references will appear in subsequent versions of the Advice.

The reviewers did not see clear value in the SWOT analysis incorporated into Section 9, generally finding it poorly incorporated. Specific comments are included in the reviewer reports, but the authors should re-evaluate inclusion of the SWOT analysis. It may be better to convert the SWOT analysis into some basic, synthesized text.

Response: The comments are noted and the SWOT analysis was not carried into the subsequent AGD report.

Individual Reviewer Reports from the Three Reviewers:

Review by Dr Seth Theuerkauf (Review Group Lead)

Big Picture Comments:

In a very broad sense, the Terms of Reference have been adequately addressed by the Workshop report authors with information coverage including the range of requested material by topic (A-E). However, there are areas of gaps in coverage that would benefit from strengthening. Generally, there is lots of great information and data presented—but there is not much by way of its synthesis into major observations, trends, or patterns.
Section 2 - History (even in a general sense) of production is not presented, or at least not consistently. This section would be strengthened with a description of when various farming practices began, their history of production growth, etc. This does not need to be extensive, as Section 3 should provide the granular detail and trend data. As an example, under Section 2.6 for Wales (page 27), it is described that 'long-running efforts to get old leases replaced' are underway – what is meant by old?

Response: The production data presented in Section 3 will go some way to identifying when production would have commenced in each jurisdiction.

Section 2 – Information on market value of production and employment is not consistently presented – for example, the sections cantered on Ireland do not include any market data, but the sections on the UK do. The Scotland section includes data on employment, for example. Section 7 on Social and Economic Context on page 68 provides some of this information. I recommend removing this information from Section 2 and relocating it to Section 7.

Response: The observation is noted and clear demarcation of subjects will be incorporated into future reports.

Section 2.9 – spend a little more time and space capturing the major gaps that were identified and opportunities for improvement. They may vary across the regions described, but there should be a few common threads that can be highlighted here.

Response: Gaps will have been dealt with in more detail in the ADG report.

Section 3 – this is all great data, but it is difficult to sift through it all. I recommend a concluding section that summarizes key trends. This currently exists in Section 7.3, but it doesn't fit appropriately there.

Response: Trends analysis was difficult to execute and was difficult to address given the time constraints and expertise at the disposal of the group.

Section 5 – inconsistent level of detail. Scotland, for example, has very little specific information on aquaculture health regs.

Response: The comment is noted and will have been addressed in detail in the ADG report.

Section 5.2 – Inconsistent level of detail on monitoring and management for Scotland, and no info for England and Wales.

Response: It was attempted to identify those monitoring programmes that were common to all jurisdictions (e.g., food safety, fish health). In addition, much monitoring and management centres around finfish activities. The majority of these occur in Scotland and Ireland.

Section 6.3 – more detail is needed for the shellfish section, especially related to genetic interactions. It is noted in multiple locations that seed are imported, have genetic interactions been studied?

Response: Some additional information included in the AGD report.

Section 9 is clear, except the SWOT analysis (what is meant by '???', what is meant by '-' in entries within the table)

Response: Observation is noted.

Review by Dr Katherine Mary Dunlop

General Comments:

In general, the report offers a well-written and thorough review of aquaculture activities in the Celtic Sea region that meet the TORs. It was well structured, easy and interesting to read. The figures and tables are in general presented well, however, some of the in-text references to figures are incorrect and I recommend that the authors consider the position of the figures and tables in relation to where they are first mentioned. For example, Figure 6.5 is referred to in the text but is not present in the document. A table presented on page 56 is not labelled or referred to in the text.

Chapter 1 begins by addressing the oceanographic conditions of the region. For the oceanography section I would suggest the addition of further linking information to show why it is relevant to aquaculture in the region, such as is done in the temperature section (1.4).

> **Response:** This is an important comment and should be considered in future climate impact scenarios of advice.

Within chapter 2, there are several sections that I would question whether they warrant the level of detail provided. For example; a high level of detail has gone into describing the methods related to oyster and mussel aquaculture, down to the diameters of the ropes and weight of concrete blocks. This is not a level of detail repeated for salmon aquaculture. Secondly, quite some details are used to described manila clam culturing however at the end it states that there are "no operators producing Manila clams in Ireland". I therefore question if the culture of this species merits several paragraphs if it is currently not farmed. Perhaps it could be stated first that they are not currently produced but were recently. This could be followed by a brief summary of what methods have been used. Finally, a high level of detail is used to describe 2 individual farms sites in Northern Ireland – down to the state of the seabed at those 2 individual sites. This seems an unbalanced level of detail and could be reduced. Minor edits to the text are suggested, mainly for chapter 2 (see specific comments below).

> **Response:** The comments are noted and in response, the chapter is primarily designed to identify those species licenced for aquaculture production. It was intended that in order to avoid repetition that in the descriptions in the later sections was to refer to the earlier section for additional detail.

In chapter 5, the monitoring and management section (5.2) does not contain information on Wales and England. In chapter 6, information on nutrient enrichment is based on Norwegian studies (Vestlandet and Trondelag). While I agree with the authors that can be relevant to Scotland, there does exists a body of literature from Scottish researchers that I would think can be more appropriate to use here. For example, work by Thomas Wilding, Kenneth Black, Lois Nickell and Thomas Nickell among others.

> **Response:** The observations in relation to the regional based information is noted and was addressed in the ADG report.

In chapter 8, I was unclear of the connection of the information presented on pages 77 & 78 to the case studies. Perhaps the role of this information is to provide an introduction. If so this could be linked better in the text. Finally, in Chapter 9, I found the SWOT analysis at the end poorly incorporated with the rest of the document. Further supporting information could be provided here to link it better within the context of chapter 9.

> **Response:** The goal of the information on Pages 77-78 was to identify some of the 'shortcomings' and issues related to licencing and management of aquaculture in marine areas. The case studies were intended to be used to summary a response to some of these

shortcomings. The comment re: SWOT analysis is noted and was not carried forward to advice report. The case studies.

Review by Dr Matthew Gubbins

General Comments:

Addresses ToRs reasonably well given the task and available data.

vi) A good, thorough if not very consistently presented overview of activity production and practices across the jurisdictional areas.

vii) The policy and regulatory frameworks are well covered but there are discrepancies in the level of detail provided between the regions. In particular, more information could be presented for Scotland.

viii) Good overview of the interactions, but leans heavily on quantified examples from Scotland giving perhaps a one-sided picture particularly for finfish aquaculture.

ix) Future projections reasonably well addressed as far as could be predicted. The SWOT analysis at the end is perhaps not the most useful way of presenting inconsistent and uncertain information.

x) Although addressed in part throughout, it is not clear that the gaps in information have been specifically addressed, particularly in relation to management. Critical for example is the uncertainty over impacts of pathogens on wild stocks, movements of fish and how that can be addressed by spatial management.

Some consistency issues in scope between national sections in the overview e.g. Food safety concerns for shellfish aquaculture addressed in some country sections, not others, nor at a ecoregion scale.

Authors have done a fantastic job of compiling different data sources to provide a picture of production trends across the whole ecoregion. This must have been a difficult task, but I am not sure Section 3.1 needs quite so much detail explaining the complexities of the source data.

Section 6 in particular is very regionally biased with much publicly available data from Scotland providing a fairly one-sided view of interactions from finfish culture.

Some sections are overly technical for a lay overview such as this. For example, section 6.3 and 8.3 reads as a scientific publication rather than for a lay audience.

> **Response:** The comments are acknowledged and many are addressed above in the specific responses. In relation to information gaps, this will have been dealt with extensively in the ADG report.

Annex 5: Advice Drafting Group Meeting Minutes

5-9 September 2022, Hybrid meeting (ICES HQ Copenhagen, Denmark and Microsoft teams)

Participants: Colm Lordan (Ireland), Marnix Poelman (Netherlands), Francis O'Beirn (invited expert, WKCSAO chair), Nicholas Stinton (United Kingdom), Marie-Julie Roux (Canada), Terje Svasand (Norway), Seth Theuerkauf (invited expert, RGAO chair), Paula Ramos (Portugal, part time), Henn Ojaveer (chair, ACOM vice chair), Michala Ovens and Anne Cooper (ICES Secretariat).

Declaration of conflict of interest: The group was informed of the ICES code of conduct and was asked to declare perceived, potential or real conflicts of interest. None of the participants declared any types of conflict of interest.

The ADG meeting started with a short introductory presentation by the ADGAO chair who introduced the ICES Advisory Framework, adoption of the agenda and suggested working procedure.

RGAO chair presented the main findings from reviewers and the WKCSAO chair responded to the major points raised by reviewers. The ADG started work on the initial draft advice prepared in advance by the ADGAO and WKCSAO chairs, which was made available for the ADG members on 29 August. The initial draft advice was prepared based on the WKCSAO draft report.

Major issues discussed and decisions taken

ADGAO welcomed and acknowledged very thorough and detailed reviews. These were considered in the advice as much as possible. Those requiring either further work or where data availability was an issue, were left out, but will be considered during the future revision process.

Delete Latin names in the text and add species table at the end of the advice. The exception to this is for marine algae – Latin names were used in place of regionally-specific common names.

Substantially reorganize several sections by summarizing/providing generic information at the beginning, and ensuring better balance between subsections and more comparable level of presentation of the details.

Production over time section: remove information on Channel Islands. Move information on cleaner fish to section on ecosystem/environment interactions.

Revise substructure of ecosystem/environment interactions and have two major sub-units (on finfish and shellfish) with broadly similar and consistent content. Remove seaweeds and indicate this as a knowledge gap.

Future projections section: add subsection on integration of different sectors, remove legislative drivers and diseases.

Small issues

Replace Figure 1 with a new map to be adapted from Ecosystem Overviews (introduction).

Delete cleaner fish and seaweeds figures (section production over time)

Add economic information on salmon aquaculture for the UK and delete Scottish shellfish businesses table (section social and economic context)

Add paragraph on diversification of existing culture systems (section future projections)