7.3 Celtic Seas ecoregion – Aquaculture Overview

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Executive summary

Aquaculture policy differs between the five countries within the Celtic Seas ecoregion; within the UK, aquaculture policy is a devolved matter with each of the separate administrations of Wales, England, Northern Ireland, and Scotland being responsible for oversight. Aquaculture production within the Celtic Seas ecoregion requires licences and is regulated.

Total aquaculture production in the ecoregion in 2018 represents 21% of the overall aquaculture production in Europe by volume and 34% by value. Total production increased from 1950 up to 2004 but has since then stabilized by fluctuating around 240 000 tonnes. Marine aquaculture production within the ecoregion is currently strongly dominated by Atlantic salmon (> 80% of the total production by volume), largely produced in Scotland. Shellfish aquaculture predominates in terms of the number of licensed sites and enterprises. Production volumes of other invertebrates and seaweeds are relatively small.

Major changes have occurred in the average price per tonne for some important cultured taxa in the last decade: mussel prices have decreased by approximately 49% while Pacific oyster prices have increased by approximately 31%. Small production units (fewer than five employees) predominate in all jurisdictions although larger, more capital-intensive operations characterize the finfish sector and are also increasing in the mussel sector. Employment status is more stable for the finfish sector than the shellfish sector. The aquaculture sector has a high socio-economic importance in rural coastal communities.

The primary environmental interactions relate to habitats and species. Sea lice and genetic introgression from farmed salmon are considered as the main threats to wild salmon populations. Other important environmental interactions considered include disease transmissions, emissions of dissolved nutrients, particulate organic matter, pollutants, and therapeutants. Increased species richness, diversity, and abundance of sessile and mobile organisms relative to ambient conditions have been observed nearby some mussel farms. The introduction of several non-indigenous invertebrate species has also been directly linked to shellfish aquaculture. Impacts on overwintering shore-birds has been described in relation to intertidal culture operations of oysters and clams.

Sustainable aquaculture growth in the ecoregion requires innovative production technologies to reduce the environmental impacts. These include the diversification of existing culture systems in response to changing environmental or biological drivers, application of diverse and innovative delousing techniques, expansion of seaweed aquaculture, diversification of fish culture species other than salmonids, and development of offshore aquaculture.

Future aquaculture development and management should increasingly consider interactions with other human activities, such as wild capture fisheries, recreation/tourism, offshore renewables, and the designation of marine protected areas. Climate change can further hamper sustainable growth and existing capacity for aquaculture in the ecoregion and alter interactions with other sectors.

Introduction

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 (Figure 1). The locations of aquaculture activities are also highly varied and range from the sheltered intertidal zone to more exposed inshore areas. As a consequence, aquaculture practices, depending on the species and systems in question, are carried out in areas from estuarine and more open coastal shorelines to deeper-water-sheltered embayments.

Nearshore and coastal habitats in the 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, particularly in estuarine areas. The prevailing physical forcing and broader environmental conditions result in highly productive waters which are considered highly suited for the production of both shellfish and finfish species.

ICES considers the ecoregion scale as the relevant spatial scale to inform ecosystem-based management.

This overview provides:

- a summary of regional and temporal information on aquaculture activities, practices, and production of the cultured taxa;
- a description of the relevant policy and legal foundation;
- considerations of the environmental and socio-economic interactions of aquaculture activities and practices;
- insights on the interaction of environmental, economic, and social drivers; and
- considerations of future projections and emerging threats and opportunities.

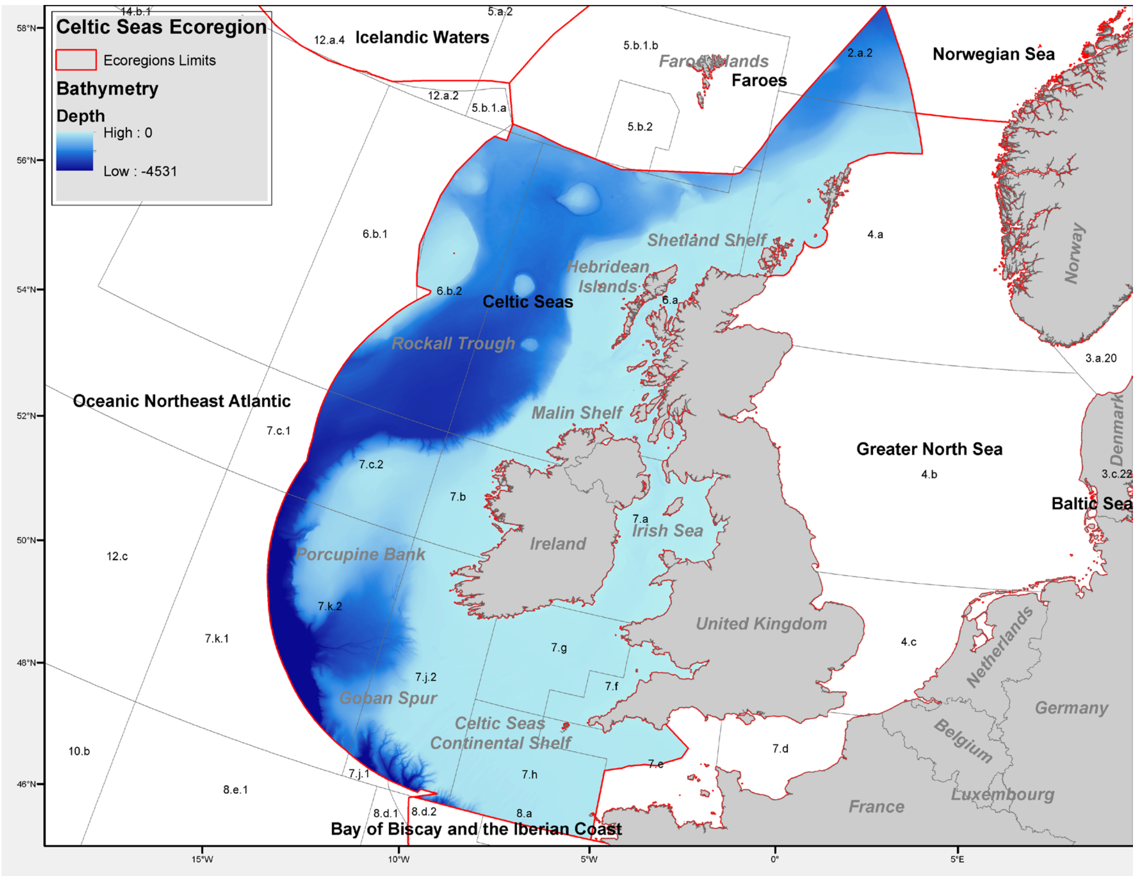

Figure 1 The Celtic Seas and adjacent ecoregions.

Description and location of aquaculture activities and practices

Marine aquaculture occurs throughout the ecoregion. The culture systems used for the production of individual species are broadly similar among the countries and are described as follows:

Shellfish – oyster

Two species of oyster are cultivated in the ecoregion: the Pacific oyster and the European flat oyster. Pacific oyster culture is carried out predominantly in sheltered intertidal areas within the ecoregion. The majority of Pacific oyster culture is 'off-bottom' using containment devices secured to trestles (tray-like structures) which allow water flow above and below the oysters. The containment devices are typically plastic mesh bags that allow water to flow in and out, thus bringing food to the oysters. The oyster trestles vary in height but typically do not exceed 0.5 m, and their height above the sediment is often less as they may sink or have accumulations of sediment over time. Oyster trestles are usually arranged in paired rows separated by about 4 m and with wider (10–20 m) access lanes. The rows are orientated perpendicular to the tideline. The sites are accessed using vehicles (with trailers) along defined routes or boats from shore-based operation sites. Oyster seed is inputted to the bags (2000/bag); as they grow the density of oysters is reduced (150–200 oysters/bag at harvest) as the mesh size increases. Where the bags or cages are fixed, they are regularly turned to prevent the build-up of fouling closing up the mesh of the bag and so reducing flow through the bags/cages. This practice of turning helps to prevent oysters from becoming 'fused' to the bags by their growing shell. It should be noted that not all oyster culture practices use bags; some culture oysters are in stacked cages or in cages suspended from trestles or longlines (suspended between poles embedded in the sediment) in intertidal areas. Production can take from 18 months to three years depending on the conditions at the site and market demands.

Bottom oyster culture (both European flat and Pacific oyster) is also carried out in sheltered areas and will typically use partially grown oysters (approximately 3 cm) from intertidal culture systems. The stock is deposited directly on the sublittoral seabed, monitored throughout the growth cycle and harvested by dredges using boats. The dredges used are typically small (1.5 m) oyster dredges. The duration of culture and size at harvest is dependent upon market requirements. There are a small number of sites that rear oysters on the seabed within the littoral zone, but is not common.

Shellfish – mussel

Mussel (*Mytilus* spp.) culture is also carried out using either suspension systems or on the sublittoral seabed. Mussel culture is concentrated primarily in sheltered embayments with sufficient water depth to accommodate suspended structures.

The culture method involves placing settlement media (rope, strap, mesh) in the water column upon which juvenile mussels settle. Depending on a number of seasonal and local factors, this will take place from April to June of each year. As the newly settled mussels grow, the seed may be moved from collection areas to dedicated grow-out areas or remain *in situ*. The collected mussel seed is then on-grown for typically 18–24 months before being harvested. Some farms grade the mussels during the 18–24 months whereby the stock is repacked at lower densities. Most of the longlines in use are double headrope longlines of greater than 100 m in length, with up to 30 floatation units (mostly grey in colour) and anchored at each end with heavy concrete blocks.

Bottom mussel culture is similar to that of oysters, where seed is deposited on the sublittoral seabed and harvested after 18–24 months. The vessels used are large and purpose-built with the capacity to deploy multiple dredges in the water at once. The stock is checked regularly for growth and predatory organisms (e.g. crabs and starfish), which are removed if found. Seed is usually introduced to the sites from traditional seedbeds (i.e. areas with predictable seed availability at certain times of the year). The seed is acquired from these areas by dredging in subtidal areas or by hand from intertidal areas. The areas within which culture occurs are typically close to those areas where the seedbeds are found. Although a more recent trend of importing seed via road has also occurred in the ecoregion.

Shellfish – other

Two species of scallop are cultured (the king scallop and the queen scallop) using a combination of suspended spat collection, lantern nets for juveniles and finished using bottom culture or suspended in nets. The Manila clam is cultured under netting on the seabed in intertidal areas.

Crustacea – lobster

The European lobster is cultured within the ecoregion. There are small number of lobster hatcheries that produce quantities of juveniles for wild stock enhancement. Such units use either pump-ashore or recirculation technologies to rear larval and juvenile stages of lobsters from wild-caught female lobsters carrying fertilized eggs on their abdomens.

Finfish – salmonids

Marine finfish farming is an intensive production method used for the culture of salmon and trout species; in the Celtic Seas ecoregion – Atlantic salmon, rainbow trout and brown trout are cultured. The sites vary from those that are sheltered to more exposed sites. Typically, production requires a suitable depth (> 20m) with good water exchange. These systems are large in scale and typically employ circular cages in gridded arrays. Standard cage diameters are 40 m, with pen depths of 15–20 m. The cages are secured to the seabed with anchors. Additional netting is deployed over the tops of cages to deter birds, while high-tension netting along the sides is used to prevent seal predation. Sites can have any number of cages depending upon space availability and licence conditions (biomass limits). The stocking density can range from 10–15 kg salmon/m^3 (10 kg/m^3 for organic status) or higher. Feed is introduced either by hand or using moored feed barges that distribute food automatically to the cages. Production cycle is varied but can typically run from 12 to 20 months, depending upon market demands or input size of smolts (larger smolts = shorter production time). Some sites are used for initial smolt input after which (approximately six months) stock is transferred to grow-out sites for finishing until harvest.

Finfish – other species

Atlantic cod, halibut, European sea bass, brown/sea trout, turbot, lumpsucker, and wrasse species are all cultured within the ecoregion. In addition to cage system production, there are also sites that utilize pump-ashore and/or recirculation technologies to rear finfish. These are generally sited close to shore/seawater source to provide either full circulation or to provide exchange water for recirculation systems. Such sites are used where the culture parameters need to be controlled/suited to the species, used for hatchery and juvenile rearing or to modify parameters such as water temperatures to improve the growth rates of fish. Salmonid species maybe cultured in such facilities, but generally these have been used to culture halibut, turbot, European sea bass, and in more recent years' cleaner fish species (lumpfish and ballan wrasse).

Seaweed

Alaria esculentia and *Laminaria digitata* are cultured within the ecoregion. Cultivation of seaweeds at sea consists of the 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. Seaweed plantlets are typically attached to the ropes in hatcheries. Some operators also rely on wild settlement of seaweed species.

<u>Ireland</u>

Irish aquaculture is primarily marine-based (Figure 2). There are a small number of inland finfish production units and several land-based shellfish and finfish hatcheries. The main species/culture groups are Atlantic salmon, farmed Pacific oyster, and suspended rope and seabed cultured mussel. Other coastal species cultured are the European flat oyster and king scallop on the seabed, and seaweeds using suspended systems.

Shellfish culture

Oyster

There are 511 intertidal licensed sites for off-bottom oyster culture. The activity also occurs in licensed areas on the seabed, where the oysters are harvested via dredging. Both the European flat oyster and the Pacific oyster are cultured in this manner, with 30 and 12 licensed sites respectively. The average size of a licensed oyster plot is 3.78 ha (range 0.07–69.4 ha).

Mussel

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. In general, the longline density is no greater than three lines per hectare. Licensed rope mussel sites have an average size of 5.78 ha (range 0.4–66 ha). There are currently 235 sites licensed for suspended mussel culture in Ireland. For bottom mussel culture, there are 89 sites licensed for production. Seed is sourced from the wild seedbeds in the Irish Sea or imported from beds in UK (following approval for health certification and risk assessment for alien species). Bottom mussel production occurs in five bays around the coast of Ireland (Lough Swilly, Carlingford Lough, Waterford Harbour, Wexford Harbour, and Castlemaine Harbour). 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 an average of around 30 t/ha. The average size for licensed bottom mussel culture plots in Ireland is 33 ha. The maximum area for a single site is 177 ha.

Other shellfish

The king scallop is also farmed in bays in the northwest and southwest (in the counties of Donegal and Kerry), using a combination of suspended spat collection, and lantern nets for juveniles and finished using bottom culture. Harvesting is done by diving. Despite there being 21 licences for the culture of Manila clams, the production of this species has been affected by the advent of the brown ring disease in production systems. There are currently no operators producing Manila clams in Ireland.

Shellfish hatcheries

Four shellfish hatcheries, based on the west coast, supply Pacific oyster seed, with 27.5 million spat units supplied in 2020. European flat oyster and scallop seed are also produced in smaller quantities by these units for local supply.

Finfish culture

There are 67 licensed marine cage sites for the production of Atlantic salmon (Figure 2); active production in 2020 only occurred at approximately 25 sites (DAFM Aquaculture database). There are three distinct regions where salmonid farming is carried out: the southwest (counties of Cork and Kerry), the west (counties of Mayo and Galway) and the northwest (County Donegal). The average area of licensed marine finfish sites is 15.7 ha (range 0.60–89 ha).

Seaweed culture

Seaweed culture is licensed at 14 sites. The main species cultured is *Alaria esculentia*. There is also increasing interest in *Laminaria digitata*.

Other species

Aquaculture licences are held for the culture of abalone and urchins, however, there has been no production for the last number of years.

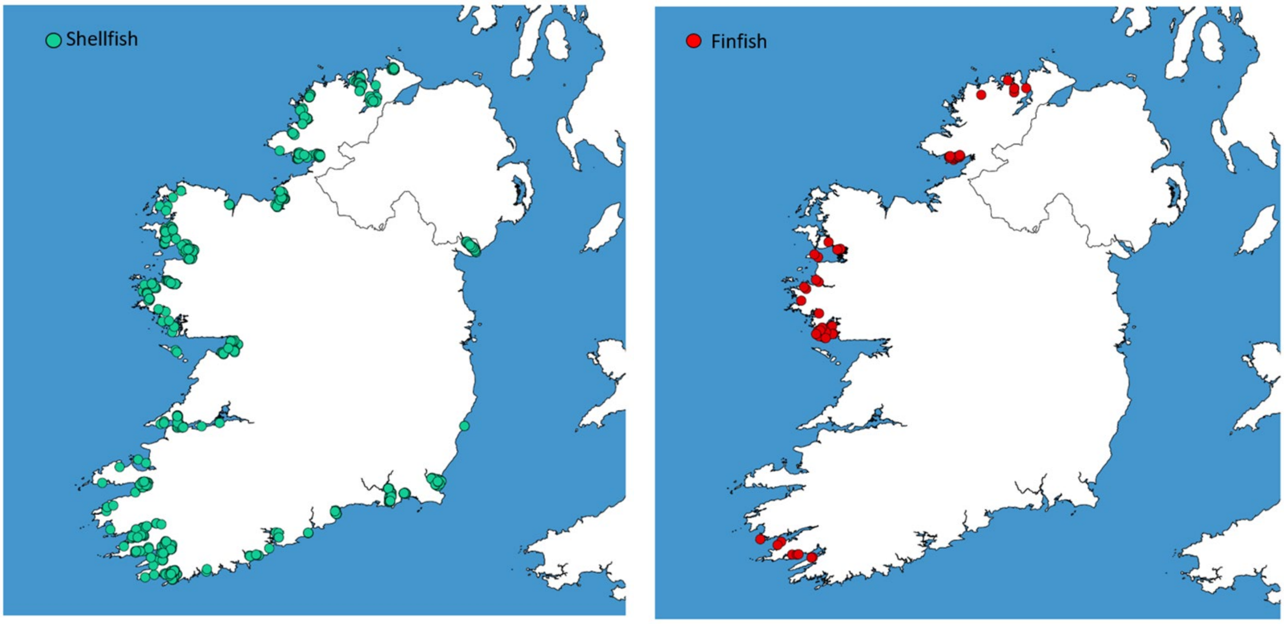

Figure 2 Shellfish and finfish aquaculture sites around the coast of Ireland.

United Kingdom

Northern Ireland

There are 28 active aquaculture producers in Northern Ireland (Figure 3). The main mollusc species cultivated are Pacific oysters, cultivated intertidally on trestles, and mussels, cultivated subtidally, with some licensed sites for suspended mussel cultivation. A shift in the main species cultivated—from mussels to Pacific oysters—has been observed over the last five years. All of the shellfish sites are located in the five sea loughs around the Northern Ireland coastline. The only marine finfish species cultured is Atlantic salmon.

Shellfish culture

Oyster

At present there are 13 licensed sites for Pacific oyster production; one of these is also licensed for European flat oysters. Site areas range from 2.5 to 51 ha. They utilize trestles positioned in intertidal zones.

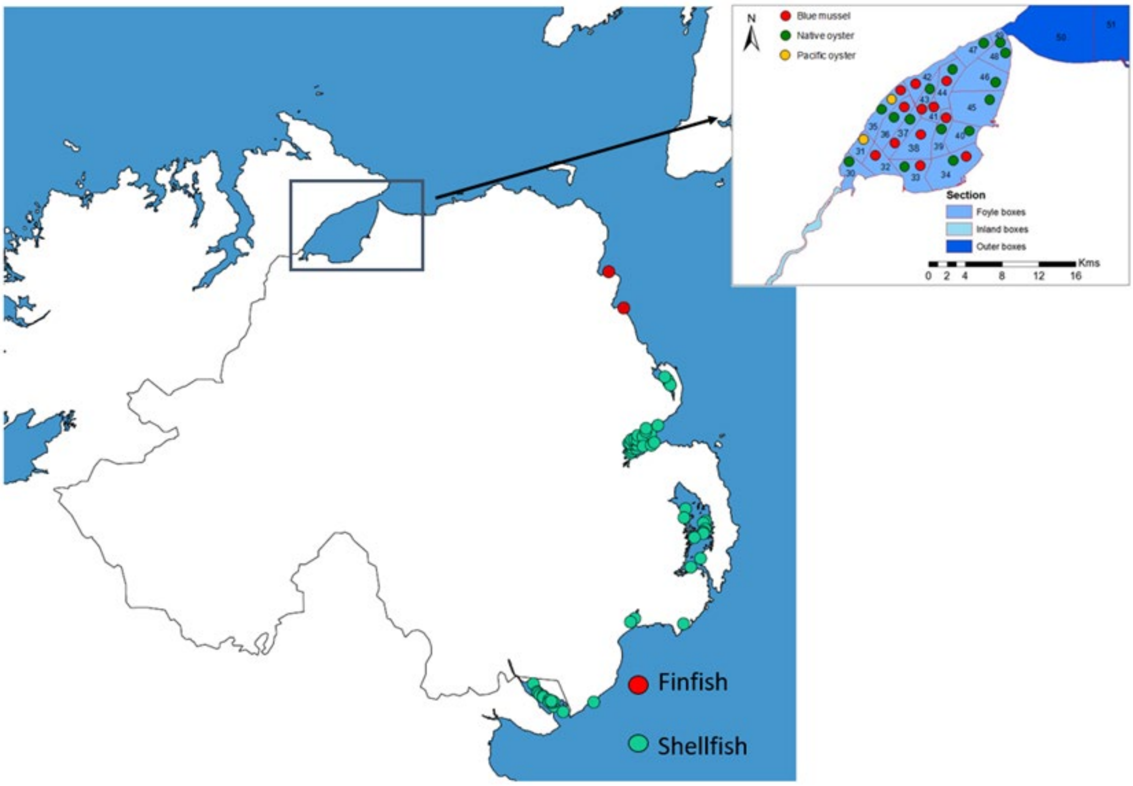

Figure 3 Licensed shellfish and finfish aquaculture sites around the coast of Northern Ireland. Insert shows aquaculture activities in Lough Foyle, the most northerly sea lough.

Mussel

Only one of the seven licensed aquaculture sites for suspended mussel cultivation in the southwest (Strangford Lough) is currently active. Mussels are also dredged from offshore naturally occurring seedbeds; seed mussel is relayed on licensed aquaculture sites in the five sea loughs. Seed mussel may also be sourced from several areas off mainland UK waters; this is usually dependent upon the availability of natural seed in both Northern Ireland and UK mainland waters.

Other shellfish

King scallop aquaculture had been trialled in a number of locations; restrictions on harvesting practices with only permits for diving to harvest have impacted the expansion of this activity.

Finfish culture

There are two salmon farm sites in Northern Irish waters off the northeast coast (North Antrim coast). Each site has a maximum of 16 circular cages, and each cage has the potential to produce 50 to 60 tonnes of salmon.

Seaweed culture

There are two licensed seaweed farms: the trial seaweed operation in the southwest (Strangford Lough), established and maintained by Queen’s University Belfast, which is not currently in production and one licenced commercial seaweed farm off the north coast (Rathlin Island), which grows kelp on longlines in a similar fashion as in Ireland.

Scotland

The majority of Scottish aquaculture is marine-based, dominated by production of salmonids (the main species being Atlantic salmon), mussels, and Pacific oysters. The majority of sites are situated along the western and northern coastlines (Figure 4) in the many sea lochs that provide sheltered areas. Other species cultured include rainbow trout, sea trout, European flat oysters, and scallops.

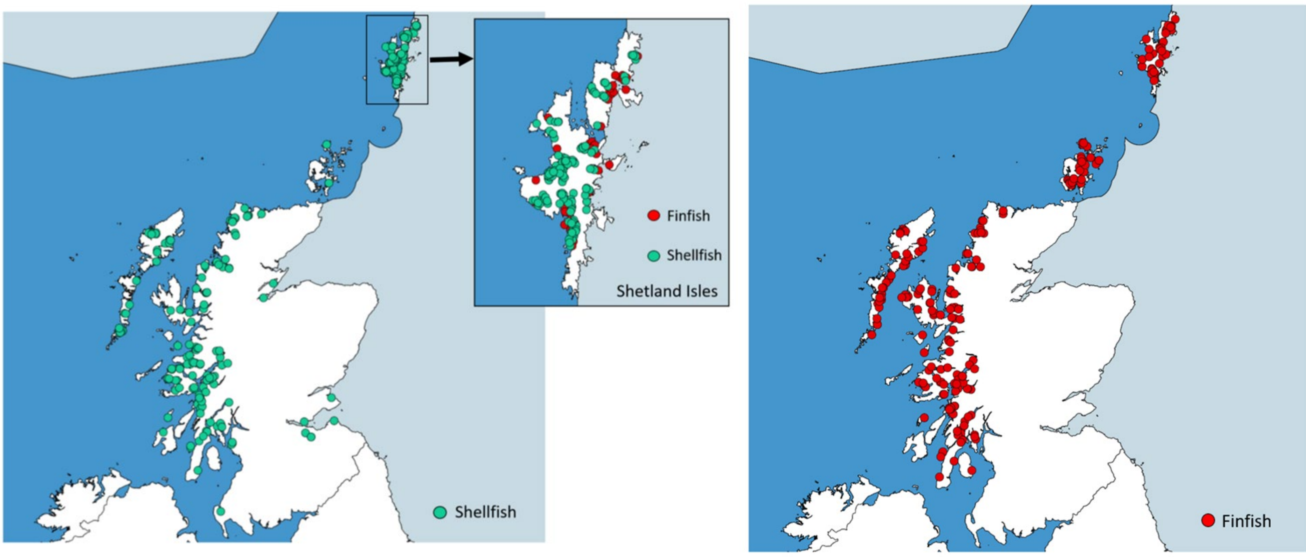

Figure 4 Shellfish and finfish aquaculture sites around the coast of Scotland. Insert shows shellfish and finfish farms on the Shetland Islands.

Shellfish culture

Oyster

Intertidal trestle sites are the most common method used for the culture of oysters with Pacific oysters being the major cultured species and European flat oysters to a much lesser degree.

Mussel

There is no bottom cultivation of mussels in Scotland; all mussels are cultured through the use of suspended ropes sited in sea lochs.

King scallop

King scallops are cultured but to a much lesser degree than oysters.

Finfish culture

In 2020, there were 78 freshwater cage sites used in the production of Atlantic salmon and 232 sites (although only 131 actively producing) used in marine production. There are approximately 50 freshwater and marine sites in total involved in rainbow trout aquaculture. Other fish species produced at a smaller scale include brown/sea trout and Atlantic halibut cultured in pump-ashore/recirculation facilities. Lumpsucker and wrasse species are also grown for use as biological controls of sea lice in salmon sea cages, and there are dedicated hatchery grow-on sites for these that use pump-ashore/recirculation facilities.

Seaweed culture

It is estimated that there are less than ten commercial seaweed farms at present.

Wales

Shellfish culture

Currently in north Wales there are five mollusc farms (mussels and Pacific oysters). In south Wales, there are six mussel farms. There is no finfish marine cage culture but there is a presence of land-based coastal finfish culture.

Oyster

Intertidal culture of oysters on trestles is located predominantly in sheltered areas along the coast (Figure 5). There is one oyster farm in the north (Menai Strait). In the south, production includes Pacific and European flat oysters in the southwest (Pembrokeshire). A European flat oyster hatchery is under construction in the north (Bangor) to support a restoration programme.

Mussel

An experimental offshore mussel longline system is operating in the north (Conwy Bay). In the south, shellfish production includes longline mussel production sited within a dock plus an offshore test system for longline mussels. In the north, farming is predominantly bottom mussel, with a ground laying of spat, making use of close proximity to the wild sublittoral seedbeds that are the primary source of seed.

Other species

There is a lobster hatchery sited in the north (Anglesey) producing juvenile lobsters for wild stock enhancement.

Finfish culture

There is no marine finfish production in sea cages, but there are two large-scale marine pump-ashore/recirculation finfish farms that are in close proximity to each other in the north. Originally designed to produce turbot and European sea bass, these are now being used to culture lumpfish and ballan wrasse as cleaner fish supply to salmon farms.

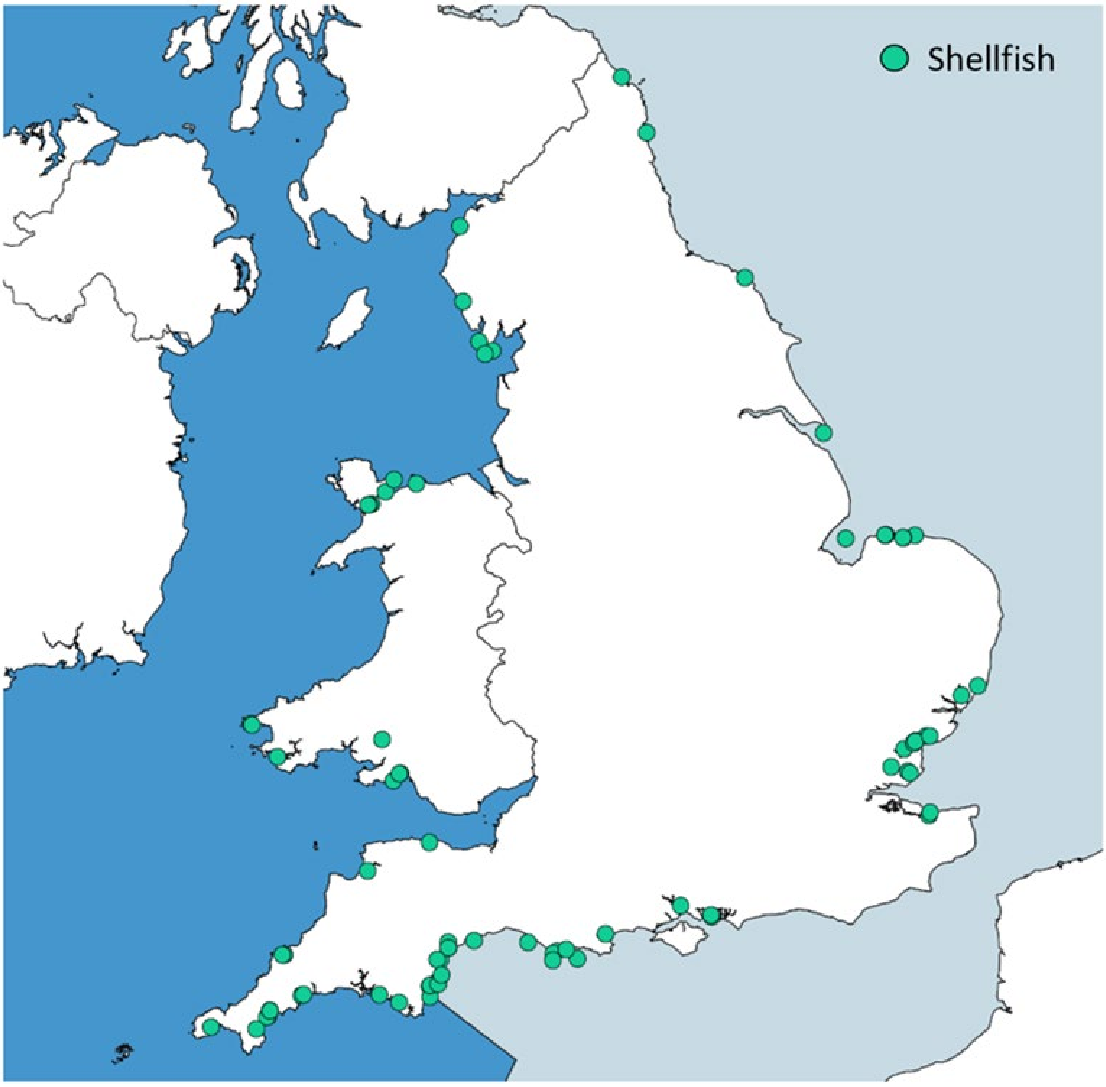

Figure 5 Shellfish aquaculture sites around the coast of England and Wales.

England

The main species cultivated on marine sites around the coast of England are mussels and oysters. There is no marine finfish culture.

Shellfish culture

Oyster

The main cultured species is Pacific oyster, which is cultivated on trestles in sheltered estuaries. There is some use of cages suspended from longlines. In addition, subtidal stacked trestle-like systems have also been used for oyster cultivation. There is on-bottom culture, mainly of native oysters in the southwest of England.

Mussel

There is one longline suspended rope mussel farm in the southwest (St. Austell, Cornwall). The majority of mussel cultivation is bottom/seabed culture, with seed mussel being fished from local wild seedbeds and relayed to licensed aquaculture sites. Mussels are harvested in the different areas by dredging and raking by hand.

Shellfish hatchery

There is an oyster hatchery in the northwest (Morecambe Bay); stock is produced in a land-based facility adjacent to the coastline for on-growing at marine sites for aquaculture and oyster restoration projects. The main species produced is Pacific oyster with native oysters and Manila clams being cultured to a lesser extent. The hatchery is a significant supplier of Pacific oyster seed for the ecoregion. Manila clam culture is limited and where it occurs is generally on-bottom in intertidal zones and gathered by hand raking.

Other species

There are lobster hatcheries sited in the southwest (Cornwall) producing juvenile lobsters for wild stock enhancement.

Production over time

Between 1950 and 2020, production of 27 taxa of finfish, molluscs, crustaceans, other invertebrates, and seaweeds was reported across the ecoregion. Statistics on mussel production started being recorded in the 1950s, followed by European flat oyster and Pacific oyster in the 1960s. Finfish production statistics started in the 1970s with Atlantic salmon, followed by rainbow trout and a variety of other marine fish species, including Atlantic cod, Atlantic halibut, European sea bass, sea trout, turbot, and haddock. Recently, wrasse and lumpfish have been produced to control sea lice on salmon farms. For both finfish and molluscs, the number of different species reported annually tended to increase up until the 2010s, but subsequently decreased since then (Panel A, Figure 6).

Molluscs dominated the production volume until the late 1980s. After this, Atlantic salmon production increased, and it currently accounts for > 80% of the total production by volume. Although several species of invertebrate and seaweed have also been cultured since 2001, relative volumes have been insignificant compared with both finfish and molluscs (Panel B, Figure 6). The total aquaculture production increased up to 2004, but has since been fluctuating around 240 000 tonnes.

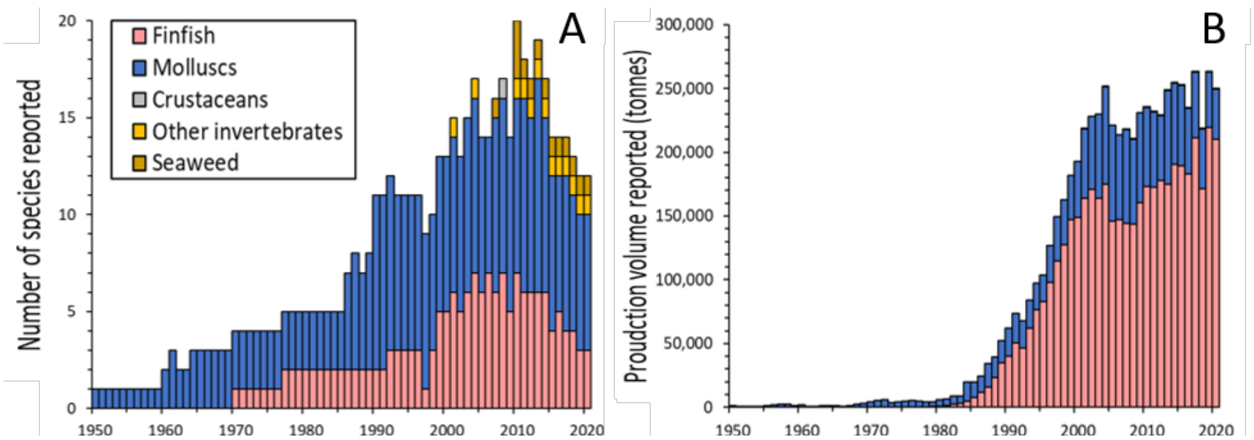

Figure 6 Time-series (1950–2020) of aquaculture production (FAO, 2022) for the Celtic Seas ecoregion, differentiated by major taxonomic grouping (finfish, molluscs, crustaceans, other invertebrates, and seaweeds). Panel A: annual number of different species reported; Panel B: annual production by tonnage.

Finfish

<u>On-grown production</u>

On-grown production of marine finfish is dominated by Atlantic salmon with a current peak of around 200 000 tonnes. The majority of the production is from Scottish waters. Rainbow trout has the second highest production volume. Other finfish species show growth in production, at around 4000 tonnes in recent years (Panel B, Figure 7).

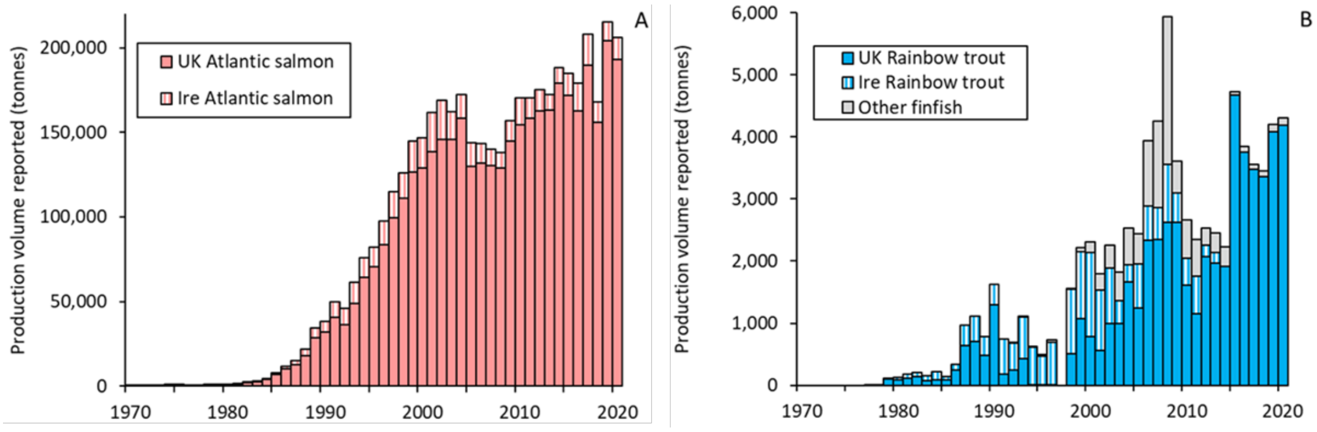

Figure 7 Time-series (1970–2020) of finfish aquaculture production (FAO, 2022). Panel A: Atlantic salmon; Panel B: rainbow trout and other species.

The other cultured finfish in the ecoregion, ranked in descending order by annual production, include:

- Atlantic cod with a peak in 2008 of 1822 tonnes; produced in Scotland;
- Atlantic halibut with a peak in 2005 of 272 tonnes; produced in Scotland (no statistics available since 2017);
- European sea bass with production of up to 500 tonnes between 2008 and 2014; north Wales;
- Sea trout with a peak in 2008 of 311 tonnes (seawater production may include freshwater production of brown trout);
- Turbot with a peak in 2004 of 258 tonnes. Turbot production has been reported for UK and Ireland. Turbot was also produced in Scotland in the 1980s with production at around 100 tonnes.
- Haddock with a single report of 4 tonnes in 2006 from the west of Scotland.

Hatchery production of cleaner fish

Hatchery production of juvenile lumpfish and wrasse in Scotland as cleaner fish for biological control of sea lice in marine salmonid farming amounted to 15 million individuals in 2020; this was associated with the starting of commercial hatchery. Production of lumpfish and ballan wrasse in Wales remains unknown.

Hatchery production for stock enhancement

Atlantic salmon and sea trout are produced in hatcheries for environmental stocking in the ecoregion. Production data are either often not collected, remain to be validated, or are confidential. The available time-series of production for environmental stocking indicates a marked decline over time (Figure 8), which is likely to be associated with changing policy on stocking.

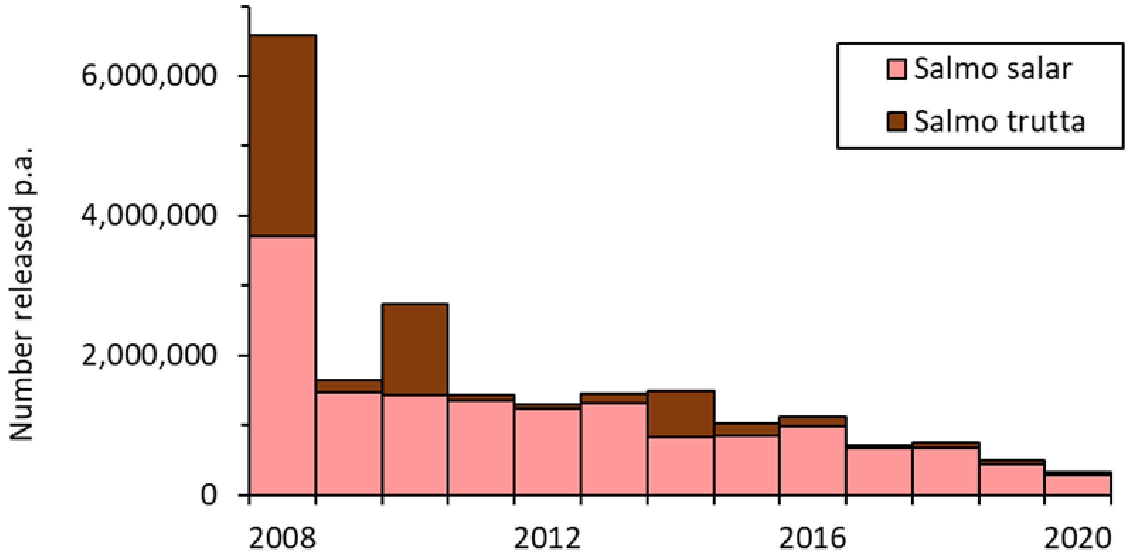

Figure 8 Time-series of numbers of juvenile salmonids produced for stock enhancement in Ireland, Northern Ireland, England, and Wales. Reconstructed from (DAERA-NI, 2018.; Ellis *et al.*, 2015; and the EuroStat database). Note that some anomalous UK data (EuroStat) are excluded, likely because of confusion between production of juveniles for stocking and on-growing.

Molluscs

<u>On-grown production</u>

Mussel statistics are available in Ireland since the 1950s and in the UK since the 1980s. Blue mussel is the main farmed species. Production peaked in 2004 at 68 000 tonnes, but has since then declined by an estimated 60% (Figure 9). Current production has been stabilized at 30 000 tonnes. Production in Ireland has been stable over the last decade, while production in the UK continues to decline.

Pacific oyster production started after the introduction of the species in the UK in 1961 and Irish waters in 1970. Production of the species is increasing across the ecoregion and is currently approximately 13 000 tonnes (Figure 9). European flat oyster has been produced in Ireland since 1960 and in the UK since 1987. Production has decreased from a peak of 900 tonnes in the 1970s to 250 tonnes currently (Figure 9).

Japanese carpet shell (Manila clam) has been produced in Ireland and UK since 1990. Production has dropped from a peak of 300 tonnes in the late 2000s to 10 tonnes currently in the UK (Figure 9).

The great Atlantic scallop has been produced in the UK since 1986 and was produced in Ireland between 1995 and 2016. Production has fallen to negligible volumes over the last 20 years from a peak of 120 tonnes in the 2000s (Figure 9).

Other molluscs cultured in the ecoregion, ranked in descending order of total annual production, include:

- Queen scallop produced in the UK since 1986, falling from a peak of 170 tonnes in 1988 to negligible current volumes;
- Northern quahog (hard clam) with intermittent production in the UK since 2003;
- Marine molluscs nei with production in Ireland and UK with unknown amounts;
- Abalones nei with minor production in Ireland during 2008–2013.

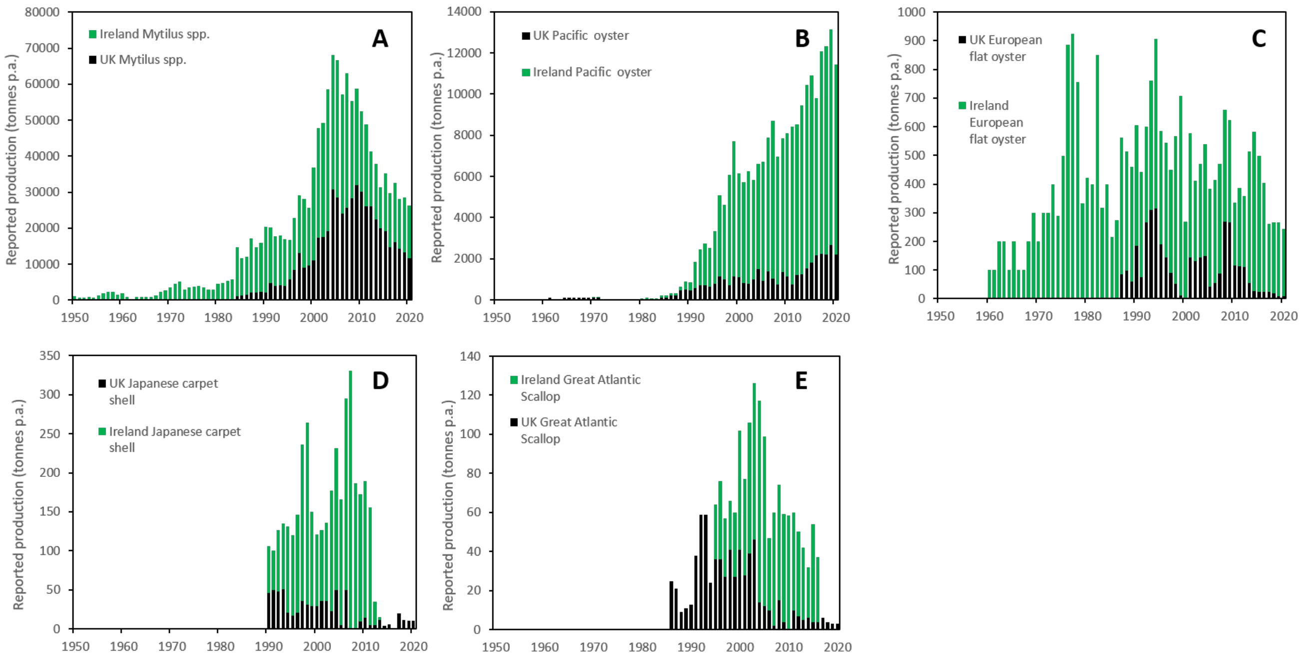

Figure 9 Time-series of aquaculture production tonnage statistics for mollusc species from Ireland and UK (FAO, 2022). Panel A: mussels; Panel B: Pacific oyster; Panel C: European flat oyster; Panel D: Japanese carpet shell; Panel E: great Atlantic scallop.

<u>Hatchery production for on-growing</u>

The majority of hatchery production in the ecoregion is to supply diploid and triploid Pacific oyster seed to the aquaculture industry. The majority of oyster seed used in Ireland derives from outside the ecoregion (France). There is also some commercial shellfish hatchery production of oyster spat in England and commercial European flat oyster hatchery in Scotland (Orkney).

The majority of mussel seed for on-growing is either derived from wild capture or is collected through mussel seed collectors (as part of the production cycle). There was also an experimental mussel hatchery pilot activity until 2018 in Shetland.

<u>Hatchery production for stock enhancement</u>

The current activity in hatchery production of European flat oyster for stock enhancement and also habitat restoration occurs in Ireland and UK.

Crustaceans

<u>Hatchery production for on-growing and stock enhancement</u>

There are hatcheries producing juvenile European lobster for release in stock enhancement in Scotland, England and Wales. Published statistics are limited to England, which indicates an increasing trend since 2001 (Figure 10).

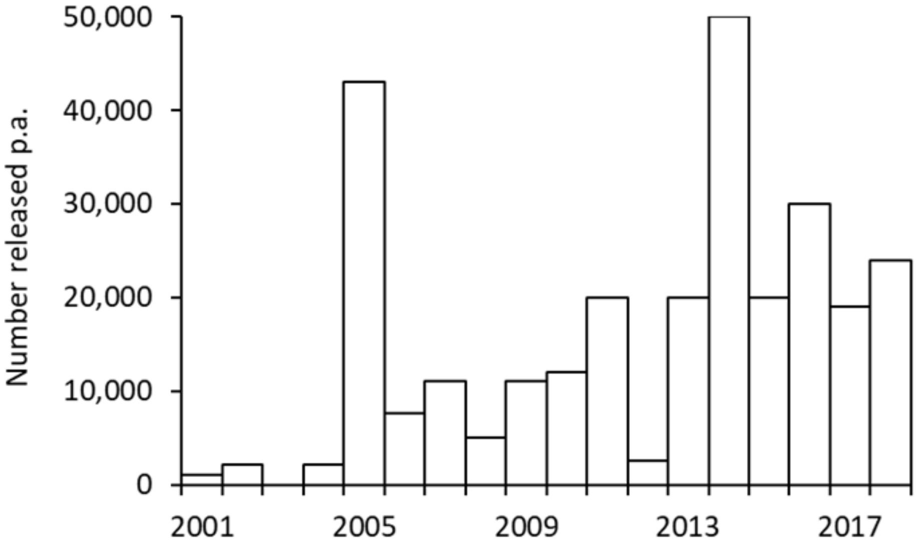

Figure 10 Time-series of production of juvenile European lobster from English hatcheries for release in stock enhancement schemes (Ellis *et al*., 2015; EuroStat database).

Other marine invertebrates

Reported production of other marine invertebrates in the ecoregion is limited to stony sea urchin in Ireland, with intermittent production of 0.5–5 tonnes between 2001–2013, and other aquatic invertebrates nei in Ireland with production of 4–57 tonnes between 2014–2020.

Seaweed

Species farmed in the ecoregion with well-developed techniques include *Alaria esculenta*, *Laminaria digitate*, and *Saccharina latissima*. Statistics on farmed seaweed production are only available for Ireland for four species (*Alaria esculenta*, *Palmaria palmata*, *Laminaria digitate*, and brown seaweeds), with current production at around 40 tonnes.

Policy and legal foundation

Aquaculture production within the Celtic Seas ecoregion requires licences. Aquaculture policy differs between individual countries; within UK it is a devolved matter with each of the separate administrations of Wales, England, Northern Ireland, and Scotland being responsible for its collective oversight. In Ireland and UK all aquaculture activities may be subject to environmental impact assessment (EIA), assessment under the EU Birds and Habitats Directives, or conditions relating to regulation on the use of alien and locally absent species in aquaculture. In certain situations, wild shellfish fisheries are managed and modified to increase production and are subject to certain aquaculture-related regulations.

Ireland

The Minister (Department) for Agriculture, Food and the Marine (DAFM) is responsible for licensing aquaculture under the Fisheries Act of 1997. In addition, applications for coastal aquaculture operations also require a foreshore licence from the DAFM under the Foreshore Act of 1933.

The licensing of aquaculture operations must engage in consultations with prescribed statutory bodies and the public. Observations provided as part of the aquaculture licensing consultations are communicated to DAFM and considered in the decision-making process. During deliberations of aquaculture licence applications, DAFM must consider wider environmental legislation, including provisions under, among others, the EU Birds and Habitats Directives and the Environmental Impact Assessment (EIA) Directive. Additionally, consideration must be given to the status of species proposed for culture, which requires that the translocation/introduction of alien and locally absent species be authorized by DAFM (subject to risk analysis).

Northern Ireland

The Marine and Fisheries Division of the Department of Agriculture, Environment and Rural Affairs (DAERA), is responsible for the granting of aquaculture licences under the Fisheries Act (Northern Ireland) 1966. There are three types of aquaculture license granted under the act: 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 farm without such a licence. A shellfishery or marine fishery licence is an optional additional licence for aquaculture operators and gives the licence holder the exclusive right to cultivate a particular species within a specified area and legislative protection for their operations.

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 must carry out an environmental impact assessment.

All applications for fish culture licences within Northern Irish jurisdiction that are within or adjacent to a marine protected area (MPA) are subject to a habitat regulations assessment (HRA). Therefore, before a new aquaculture site within or adjacent to an MPA can be licensed it must first be demonstrated (by means of an HRA) that the proposed site will not impact the conservation objectives of the designated site in question.

There are two transboundary sea loughs which border Northern Ireland and the Republic of Ireland (Carlingford Lough, in the northeast of the island of Ireland, and Lough Foyle in the northwest). Aquaculture licensing is currently carried out by the respective national body. A separate authority has been identified for the regulation of aquaculture practices in these waters; however, the powers to regulate have not been assigned to this body as of yet.

Scotland

All aquaculture businesses must be authorized by Marine Scotland. From 2007, all new fish and shellfish aquaculture development within Scotland requires planning permission 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 applications are 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 an 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 are enforced by the Scottish Environmental Protection Agency (SEPA).

England and Wales

There are a number of organizations involved in the aquaculture consenting framework in England (e.g. DEFRA), and regulations are dependent on the nature of the farm. Planning permission is required from the local authority along with land use consent from the Crown Estate or other land owners. Marine development or construction licences are required from the Marine Management Organisation. Abstraction licences are needed from the Environment Agency, with the local authority granting permissions related to food hygiene and safety. It is an offence to operate an aquaculture facility without authorization from the Fish Health Inspectorate under aquatic animal health regulations. The alien and locally absent species in aquaculture regulation may also be applicable.

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. Consultations are also needed with Natural England and the local Inshore Fisheries and Conservation Authority (IFCA).

In some areas where aquaculture and reseeding activities take place, the Shellfish Act (1967) makes provision for "the establishment or improvement, and for the maintenance and regulation, of a fishery for shellfish." 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."

Management frameworks

In Ireland and Northern Ireland, animal health legislation governing the management of fish health on shellfish and finfish farms is wide-ranging and derives primarily from EU legislation. In Scotland, England, and Wales, aquatic animal health legislation was originally derived from EU legislation and has been adopted into national law since the withdrawal of UK from the EU. However, the overall aims of the legislation for all jurisdictions are similar, outlining parameters for the prevention and control of aquatic animal diseases and also requiring operators of all aquaculture establishments to be approved by or authorized by the competent authority. They outline monitoring programmes for listed notifiable diseases and other aquatic diseases of national importance. To this end, a number of notifiable diseases are routinely monitored for in both finfish and shellfish. All establishments must operate in accordance with an approved biosecurity measures plan, which is generally developed by the business and regulator, with the latter possibly providing guidelines on how this should be created and in line with larger strategies. Operators in all jurisdictions are subject to a number of licence or authorization conditions, which may include generic conditions such as mandatory record keeping of movements on/off a site to facilitate disease tracing as well as specific conditions that may be site- or species-specific.

There may be any number of additional management frameworks in operation that are designed to manage human activities and, in specific instances, aquaculture activities. Many of these programmes have a statutory basis and 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 aquaculture species and how they are contained or managed. In addition, the output from aquaculture must be safe for consumption by humans. The impact of aquaculture practices on other species and the environment are also managed with a view to being minimized.

Monitoring to ensure aquaculture products are safe for consumption and, in particular, are free from contamination is focused on the likely risk of contaminants (i.e. chemicals, non-permitted or controlled therapeutants, and trace metals in shellfish flesh and seawater) and the presence of biotoxins in shellfish. Shellfish are monitored for the amount of marine biotoxins that may be present for the protection of consumers. To this end, mollusc samples from all mollusc production areas are regularly analysed.

Ireland

Around the coastline, there are zones that are classified as infected with particular notifiable diseases as well as zones that are classified as disease-free. In order to protect the disease-free zones, there are restrictions put in place to restrict the movement of susceptible and potential vector species between zones.

For salmon finfish operations, sea lice pose a particular issue, and the management of the parasite remains an ongoing challenge for operators and regulators. Management programmes have evolved from the 1990s as a result of various research and reports and have continued to be updated on the basis of national and international developments. The Marine Institute and Department for Agriculture, Food and the Marine (DAFM) are responsible for sea lice management. Should the lice threshold on farmed salmon be exceeded, the farm is instructed to act, which may result in treatment with chemotherapeutants, accelerated harvesting, or the complete removal of stock, among other actions.

Northern Ireland

The Agri-Food and Biosciences Institute (AFBI) undertake monitoring of shellfish aquaculture sites to ensure compliance with Habitat Regulations Assessment and fish culture licence conditions on behalf of the Marine and Fisheries Division of the DAERA. It uses ecosystem modelling 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.

In order to ensure that any changes in benthic sediments and communities remain small and localized, a programme of monitoring has been established for all new intertidal oyster aquaculture sites granted in recent years. If changes in sediments are detected, then further infaunal samples are collected for baseline comparison and management options explored.

Scotland

The competent authority in Scotland is Marine Scotland (MS), whose Fish Health Inspectorate (FHI) undertakes disease monitoring programmes, assessments for disease control, sea lice management, and containment measures. Scotland has a robust legislative and regulatory framework in place which aims to achieve a balance between growing the fish farming sector and protecting the marine environment on which the sector depends.

In response to expansion in the finfish industry the management framework associated with finfish aquaculture has evolved into a revised regulatory framework for protecting the marine environment from discharges from fish farms. The framework is subject to ongoing review and revision by an established stakeholder group. The system continues to define the likely impact of salmon farming on the marine environment. Operators are required to demonstrate that they stay within permit limits set to control the quantities of organic wastes and medicine residues released into the marine environment. To this end, operators are required to monitor the benthic biota and medicine contaminants found therein. The monitoring outputs are separately audited and analysed for trends by the Scottish Environmental Protection Agency.

Escapes are a particular concern of salmon culture, and so any suspected escape from a fish farm, or circumstances which give rise to a significant risk of escape, must be reported to the FHI.

Sea lice are also a major concern, and as such specific legal powers confer the FHI to carry out inspections, examine sea lice records, and assesses the measures in place to prevent, control, and reduce parasites on farms. The Scottish aquaculture industry are required to demonstrate satisfactory measures are in place for the prevention, control and reduction of sea lice on farm sites. Operators are required to report the weekly average adult female sea lice numbers per fish on farm sites to Scottish Ministers no later than eight days after the end of the reporting week. FHI monitoring of the farms will result if threshold levels of lice on fish are exceeded. The farm is subject to series of management actions in order to reduce the levels below the threshold levels

England and Wales

The Fish Health Inspectorate (based at the Centre for Environment, Fisheries and Aquaculture Science [Cefas]), who report to DEFRA, is the competent authority; its main responsibility is to assess and authorize new aquaculture production businesses (APB) to undertake monitoring programmes for notifiable and emerging diseases and to implement official controls to prevent the introduction and spread of serious diseases in fish, molluscs, and crustacea.

There are multiple disease zones (for mollusc diseases) around the coastline, which include many of the main mollusc production areas. All zones are subject to official control measures aimed at preventing the further spread of disease from these zones. These controls include mollusc farms and depuration (cleansing) units.

Marine sites may also be subject to habitat risk assessments (HRA), particularly if they fall within a Special Area of Conservation (SAC), Special Protection Areas (SPAs), and/or RAMSAR sites. An HRA is an evidence-based assessment of the implications of any new plan or project capable of affecting the designated interest features of a European Marine Site (made up of SAC/SPA). An assessment is a process starting with a test of likely significant effect (TLSE), which is designed to assess whether the proposed activity will have an impact on the designated habitat and species features of an SPA/SAC.

If a potential impact is identified, then an appropriate assessment is carried out to provide more detail and mitigation measures. In most cases, the FHI will undertake an HRA.

Ecosystem and environment interactions

Throughout the ecoregion, there are several finfish, bivalve, and seaweed species cultured, and each has distinct interactions with the marine environment and wider ecosystem which largely result from their respective production methods. The sections below describe some of the better-known interactions.

Finfish aquaculture

Disease interactions

Sea lice are a major parasite of cultured Atlantic salmon and the most abundant parasite to affect farmed salmonids. They are widely distributed throughout most farmed salmon-producing countries, including Scotland and Ireland, where they cause multi-million-pound commercial losses to the salmon aquaculture industry. Interactions with wild salmon stocks are an ongoing concern. Sea lice from salmon farming do appear to cause mortality on migrating wild smolts and therefore, influence marine survival; however, the ecological- and population-level consequences of this impact are not fully quantified.

There is potential for transmission of other disease vectors between farmed and wild stocks, in particular infectious salmon anaemia (ISA) and pancreas disease (PD). Outbreaks of ISA are few. Cross infection of ISA and wild fish can occur as during an outbreak of ISA in Scotland in 1998–99. Ireland is free of ISA. The first description of PD in farmed Atlantic salmon was from Scotland in 1976. The disease has now become endemic in Ireland and parts of Norway and continues to be significant in Scotland. Amoebic gill disease (AGD) has been reported in Scotland and Ireland in recent years.

Genetic introgression

Escapes of farmed salmonids in Scotland are presented in Figure 11. All incidents of escapes in Scotland are statutorily reported under regulation and publicly available.

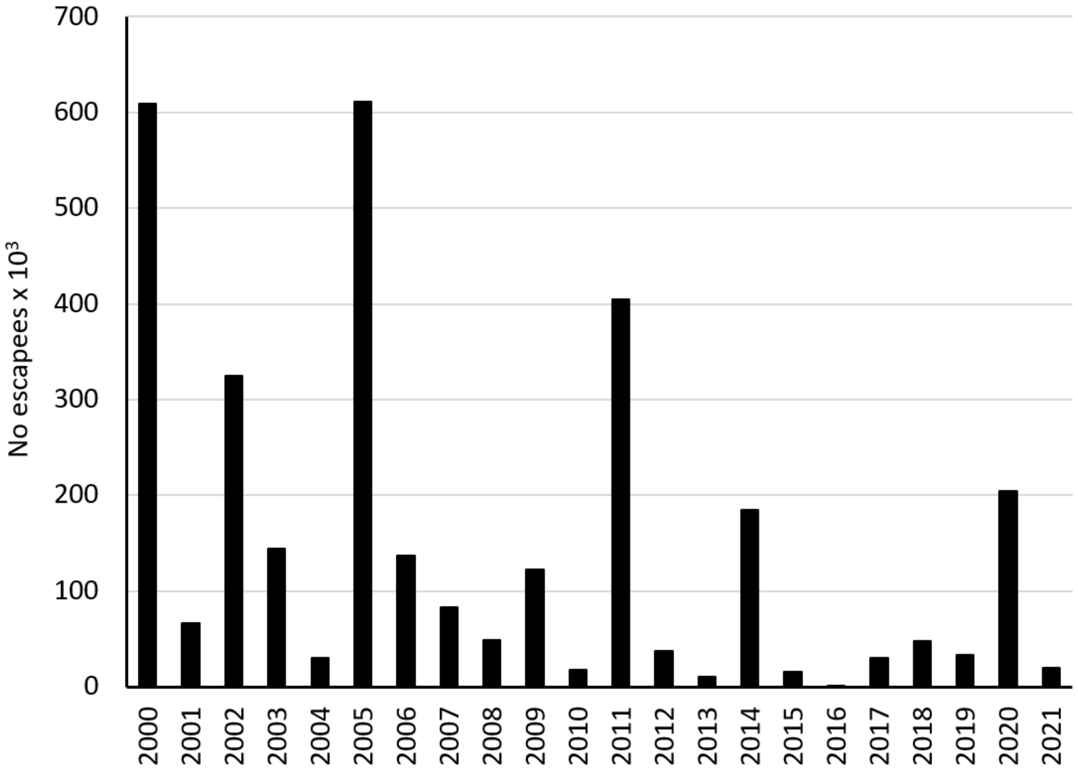

Figure 11 Reported escaped Atlantic salmon from Scottish farms, 2000 to 2021 (Scottish Government database on fish escapes; 2022).

A recent assessment on the influence of farmed salmon escapes in Scotland found that of 252 freshwater and marine sites examined, 237 were classified and ranged from good (no genetic changes observed) to very poor (major genetic changes detected). Overall, the classification throughout Scotland found 77% of sites were classified as good, 9.5% as moderate, 8.4% as poor, and 6% as very poor. There is evidence that introgression of genetic material from farmed salmon has altered the genetic composition of some wild populations within rivers near aquaculture production sites.

In Ireland, no major escapes have been reported in recent years. While some introgression has been observed in Irish rivers, the ecological consequences of this have not been determined.

<u>Farm effluents</u>

One of the primary and most documented impacts on both local and wider ecosystems from marine fish pen culture is the effect of release and distribution of excess nutrients. These nutrients can be both soluble and particulate in nature and result from excretion, faecal release, and deposited uneaten food. In Scotland, dissolved nutrients have demonstrated an increasing trend of discharge (Figure 12). 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 on the seabed within the vicinity of the fish farm, creating zones of effect on sediment biodiversity. Conditions and severity of effects change within seabed sediment ‘downstream’ of the fish farm in the main tidal flow directions. Impacts can occur through smothering by deposited material or by the incorporation of elevated levels of nutrients into sediments. Nutrient-enriched conditions often occur directly beneath the farm resulting in depleted oxygen conditions and low benthic animal diversity. Benthic effects grade progressively with distance from the farm, achieving natural conditions within 200–1000 m away, depending on the hydrodynamics of the site, the size of the farm, and the sensitivity of the benthic habitat. In fast-flowing conditions, finer faecal particles can disperse more widely and be found up to 2 km from the farm.

In order to prevent biofouling of net pens, antibiofoulants in the form of paints and coatings are used. The main active antibiofoulant ingredient used in these coatings is copper, which leaches out to prevent settlement. It has been estimated that 80% of the treatment leaches into the adjacent water column between coatings. Copper use as antifoulant treatment in Scotland peaked in 2012 and has decreased in use since (Figure 12).

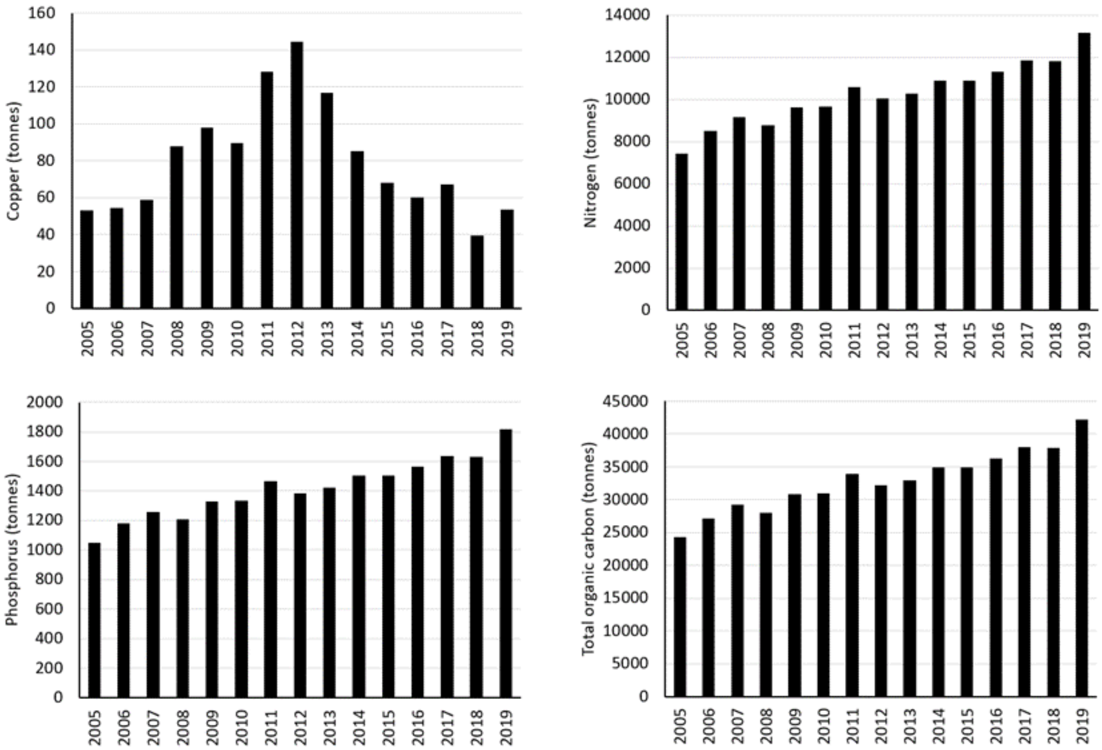

Figure 12 Total copper discharged and calculated nutrient emissions from Scottish fish farms, 2005 – 2019 (Scottish Government, 2021).

Chemical treatment

A number of chemicals are used for therapeutic treatment of disease or maintenance of structures when farming salmonids in coastal net pen systems. Therapeutants are used primarily for the treatment of bacterial diseases (antibacterials) or against parasites. Anti-sea lice compounds are the most commonly used chemical treatment in the ecoregion (Figure 13). In Ireland, the use of chemotheraputents is carried out under veterinary supervision, and while records may be subject to review by authorized officials, they are not published broadly. It is noted, however, that the use of non-medicinal treatments is becoming more common.

Figure 13 Total amounts of anti-sea lice treatment used in Scotland 2002 – 2021. Panel A infeed treatments; Panel B: bath treatments (SEPA, 2022).

Use of cleaner fish

Wild wrasse species are caught from coastal waters around Ireland, Scotland, and southwest England for deployment as cleaner fish in salmon net-pens for the biological control of sea lice. This use of wild wrasse started in the late 1980s/early 1990s and although the practice then largely stopped when new chemotherapeutants were introduced, it returned in the mid-2010s. There are five species of wrasse used in Scottish salmon farming (rock cook, goldsinny, cuckoo, corkwing, and ballan). Verified statistics on the input of cleaner fish to aquaculture are generally lacking.

The use of cleaner fish for delousing is common in the salmon industry and is considered as a low impact method of lice control. Cleaner fish also pose little direct welfare risk to the salmon compared to chemical delousing and especially mechanical and thermal delousing. In general, the current use of cleaner fish is subject to high mortality rates among the cleaner fish, which raises animal welfare concerns. Also, increased fishing for these species in the wild (for ballan wrasse in particular) may impact on local populations. Finally, relocating cleaner fish over long distances presents risks to local wild (cleaner) fish populations in terms of the transmission of pathogens and genetic introgression in the event of cleaner fish escapes.

Marine mammals

Marine mammal populations interact with finfish farms, 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 UK population), and around 26 900 harbour seals (82% of UK population; Scottish Government, 2019). Predation by seals is an economic and welfare concern to the fish farms, and it potentially leads to escapes of farmed salmonids. Such interactions have led to the lethal removal of seals, which has been regulated in Scotland since 2011 and 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 covernetting. Both of these are used widely, but it is recognized that ADDs may cause disturbance to cetaceans.

In Ireland, interactions between marine mammals and farms are considered rare. Permits may be issued to shoot seals considered problematic on salmon farms. Since 2016, three such permits have been issued.

Seabirds

The environmental impacts of aquaculture activities on seabirds may include risk of entanglement (in the net-pens and bird netting) or interactions with marine debris. In addition, the productivity and health of seabirds can be affected by their foraging on fish feed. Possible hazards to seabird populations include disturbance/displacement from farm areas as a result of activities such as noise from farm vessels and lighting, among others.

Throughout the ecoregion the consideration of the potential interactions between aquaculture operations and conservation features (e.g. Natura 2000 sites) is an ongoing issue. Specifically, evaluations of interactions with bird species continue to be constrained by a lack of empirical data on responses and methods to assess these interactions.

Shellfish aquaculture

Disease

The proliferation and spread of high impact parasites and epizootic pathogens have been associated with the spread of cultivated shellfish. For example, the transfer of Pacific oysters from France to Ireland has been linked with the introduction of the oyster herpes virus into the ecoregion.

Genetics

Increased risk of hybridization in mussels has been identified in some instances likely a result of movement of aquaculture stock among different areas in the ecoregion.

Treatment

There are no known chemical treatments associated with shellfish culture operations.

Seabirds

While predation by molluscivorous sea ducks is a widely acknowledged problem for mussel farmers, it has not been documented as an issue in the ecoregion. Suspended mussel culture structures were concluded to have a positive or neutral effect on some seabirds.

Structures and activities associated with intensive intertidal oyster aquaculture production have been documented to cause measurable displacement of some shorebird species in the ecoregion.

Habitat interactions

Mollusc aquaculture can play a role in altering local ecosystem metabolism, where farms may utilize a large proportion of productivity. Aquaculture activities may have several additional localized impacts, such as on pelagic and benthic communities and habitats, including local hydrodynamics and dynamics of nutrients.

The scale and magnitude of deposition of organic materials below suspended culture operations depends on farm density and size, distance to the seabed, hydrodynamics, water column stability, resuspension frequency, and local sedimentation rates. Mussel farming can have negative effects, in particular when the farms are large and dense. In the Celtic Seas ecoregion, studies have demonstrated the accumulation of organic matter beneath mussel culture operations. Negative impacts on benthic communities, however, either remain to be fully demonstrated or are considered negligible and confined very closely to the footprint of the structures. In certain instances, increased species richness, diversity, and abundance of sessile and mobile organisms relative to ambient conditions, specifically finfish and starfish, have been documented.

Targeted studies at numerous intertidal oyster locations demonstrated that there were no changes resulting in sediment faunal or geochemical parameters beneath trestles when compared with control locations in Ireland; however, the impact on benthic infauna was demonstrated along transport routes across the intertidal areas within and to the culture sites. It is expected that any biodeposits resulting from culture organisms are advected from the site, given that many of the sites are macrotidal and thus considered well flushed.

The Pacific oyster is established as a non-indigenous species in the ecoregion and is found predominantly in areas proximate to Pacific oyster cultures. Several secondary introductions accompanying transfer of bivalves have also been widely reported in the Celtic Seas. Several non-indigenous or cryptogenic species were considered to be introduced by aquaculture practices to the ecoregion, with species of particular concern being the carpet sea squirt, leathery sea squirt, slipper limpet, Asian shore crab, and Chinese mitten crab. In response, the British-Irish Council has established an Invasive Non-Native Species (INNS) subgroup to develop aquaculture biosecurity protocols for these species.

Capture of wild mollusc seed is important for the aquaculture production in the ecoregion, particularly for bottom mussel culture. Input of wild mussel seed declined during 2008–2020 and is currently below 10 000 tonnes (Figure 14). In addition, Ireland has reported inputs of 375 tonnes of European flat oyster from Denmark in the period of 2008–2009.

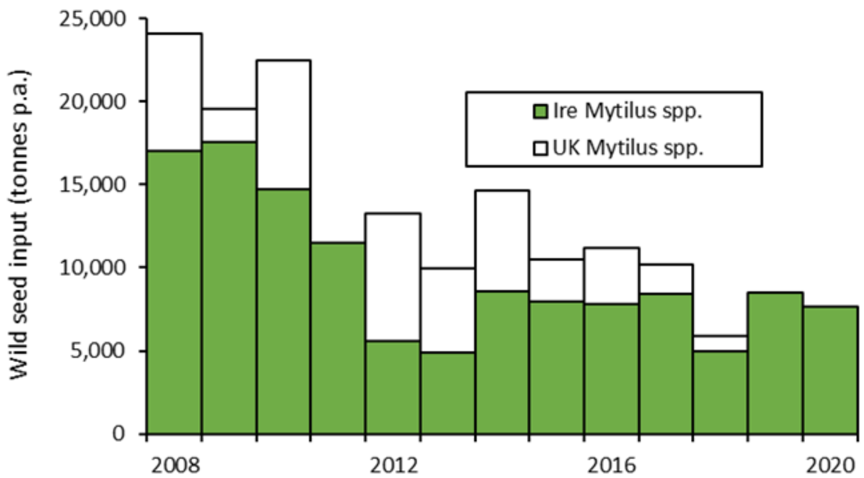

Figure 14 Time-series of input of wild mussel seed to aquaculture (EuroStat database) in the Celtic Seas ecoregion. Note: data lacking for UK during 2019–2020.

Interactions and overlap of bivalve culture with seagrasses may shape the effects of shellfish aquaculture on native communities and habitats. Shellfish aquaculture has been demonstrated to negatively impact seagrass dominated habitats, but there are no observations in the ecoregion. However, it must be noted that the licensing processes in the ecoregion will be guided by the likely sensitivity of the receiving environment. Biogenic communities such as seagrasses (as well as maerl, among others) are unlikely to have aquaculture activities licensed over them.

Aquaculture operations use a wide range of materials made of a variety of plastics. Oyster bags and anti-predator netting as used in clam culture may be a source of plastics pollution.

Social and economic context

Total aquaculture production in the Celtic Seas ecoregion represents 20.6% of the overall aquaculture production in Europe (at 227 000 tonnes of live weight) and 34% of the total European value (at 1.27 billion EUR). The main cultured taxa by value are salmon, oysters, and mussels. During 2013–2018 and throughout the ecoregion, the average mussel price per tonne dropped by approximately 49%, while an increase of approximately 31% was observed for Pacific oyster.

Economic context

Ireland

The aquaculture sector in Ireland involves mainly small enterprises. The total aquaculture sector output for Ireland has varied between 43 200 and 37 600 tonnes per annum (tpa) between 2008 and 2018, with a total farm gate sales value of between 116.9 million and 177.8 million EUR, respectively. Unit value has steadily increased for the farmed salmon and oyster segments. For salmon, output volume and value are determined by the cyclical nature of Atlantic salmon production, the fallowing and unit capacity requirements of organic certification, and by a shortage of available licensed sites. The farmed oyster segment has grown steadily (since 2008) in licensed capacity, output volume, unit sales value, and number of businesses. The output level for the rope mussel segment has remained variable with no trend, with market supply disrupted at times by biotoxin closures. Most if not all suitable sites for this segment are either already licensed or otherwise used. The seabed mussel segment has declined in output in recent years as the wild seed settlements it depends upon for input stock have become increasingly scarce. The number of businesses in the rope and seabed mussel segments are decreasing as a result of amalgamation.

United Kingdom

UK aquaculture is dominated by Atlantic salmon farming in Scotland, operated by a few large companies, whereas in England, Wales and Northern Ireland marine aquaculture production is largely of shellfish and involves mainly small enterprises. The total aquaculture sector output for UK has varied between 171 500 and 177 600 tpa between 2008 and 2018, with a total farm gate sales value of between 613.8 million and 1 032 million EUR, respectively. The total value of the UK aquaculture sector decreased in 2020, in part due to lost trade as a result of the COVID-19 pandemic as well as the withdrawal of the UK from the EU.

In Scotland, finfish production dominates in terms of production and overall value (approximately 1 000 million EUR in 2018). The total value of the Scottish shellfish sector in 2018 was approximately 10.7 million EUR, of which mussels were the most valuable part (at 8.8 million EUR), followed by Pacific oysters (1.7 million EUR) and European flat oysters (101 000 EUR). In Northern Ireland, in 2018 the combined aquaculture industry was valued at approximately 13.1 million EUR, with the salmon sector contributing 42% of this total value (at 5.5 million EUR), the oyster sector 26% (3.4 million EUR), the trout sector 17% (2.1 million EUR), and the mussel sector 16% (2.1 million EUR).

Production units

During 2018, 275 and 251 enterprises were recorded as operating in marine aquaculture in Ireland and UK, respectively (Table 1). Small production units, often employing fewer than five people, predominate in the ecoregion. However, more capital-intensive operations (i.e. primarily the finfish sector) tend to operate multiple production units and employ considerably more people per enterprise. A shift from small businesses to fewer, more capital-intensive full-time operations, is currently seen in the rope mussel sector – and less so in the oyster sector – in all jurisdictions.

Table 1 Summary economic and employment statistics for UK and Ireland aquaculture outputs during 2018 (EuroStat database). Please note that the shellfish sector statistics in 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.

	Number of enterprises		Employment numbers	Full-time equivalents (FTEs) number
	Shellfish	Finfish		
UK	205	46	2560	2259
Ireland	249	26	1932	1070
Total	454	72	4492	3329

	Sales value (EUR [$\times 10^6$])		Gross value added (EUR [$\times 10^6$])	
	Finfish	Shellfish	Finfish	Shellfish
UK	1000	32.1	256.8	14.6
Ireland	119.6	58.2	23.1	32.6
Total	1119.60	90.3	279.9	47.2

In Scotland, there were 125 authorized and active shellfish businesses in operation in 2020. Of these, ten produced nearly 80% of total mussel production, whereas four were responsible for more than 70% of Pacific oyster production. In 2020, there were eight companies and 131 actively producing marine sites for Atlantic salmon (Munro *et al*., 2021b), with six producing 99% of farmed salmon in Scotland. There are up to 21 companies involved in rainbow trout aquaculture with about 50 freshwater and marine sites in total.

Employment

The aquaculture industry provides stable or increasing employment opportunities in both Ireland and in UK and is considered an important economic contributor to rural and more isolated regions in both jurisdictions. The increase in employment in the overall aquaculture sector between 2008 and 2018 was 3% in UK and 6% in Ireland. Employment in the shellfish sector in Ireland has remained constant (approximately 1700 persons), while the finfish sector has gradually increased year-on-year. Similarly, the finfish sector in UK has seen a small growth in employment numbers, whereas the shellfish sector has declined slightly. The farmed salmon industry accounts for 55% of people employed in the aquaculture sector in UK, compared to 12% in Ireland. The number of full-time equivalents (FTEs) in the salmon sector represents 76% of overall employment numbers for this sector in Ireland, and 91% in UK. In contrast, proportions of FTEs for the shellfish sector are 46% in Ireland and 35% in UK, indicating that this sector relies heavily on part-time and/or casual labour.

Social context

The lack of a social licence for the aquaculture industry (particularly the salmon sector) is considered a major constraint to aquaculture development, operation, and management in the ecoregion, with other aquaculture sectors perceived negatively by association. In both the UK and Ireland, there is a lack of acceptance among certain NGOs, academics and private individuals, who continually challenge the licensing process and express concerns over environmental and ecological impacts and a perceived lack of regulatory oversight. Licensing and regulatory bodies will take a different view, citing a stringent licensing process and subsequent regulation of operations.

Interaction of environmental, economic, and social drivers

In addition to aquaculture, different human activities operate in coastal regions of the Celtic Seas ecoregion. These include the fisheries, tourism, shipping and energy sectors, which provide the regional context for interactions among environmental, economic, and social drivers relevant to the management and further development of aquaculture. Interactions between sectors include direct ones through competition for space and indirect ones through impacts on the environment as well as social and economic interactions across different spatial scales.

Interactions between aquaculture and wild fisheries include: i) the exclusion and displacement of fishers from fishing grounds used for aquaculture activities, ii) snagging and/or infrastructure damage (e.g. entanglement of pots with aquaculture ropes, gear trawled through aquaculture sites), iii) the transfer of sea lice and other parasites or diseases from farmed to wild fish stocks, iv) interactions between farmed and wild species (e.g. attraction/displacement of adult wild fish and/or consumption of fish eggs/larvae by farmed organisms), v) pressure on land-based resources, including harbour facilities, and vi) potential indirect competition between market products and by-products. Positive interactions include improved/shared access to marine, coastal, and land-based facilities and infrastructures, employment (e.g. fishers providing vessel services to aquaculture sites), and knowledge transfer and common market development.

Impacts of aquaculture on the tourism and recreation sector (e.g. boating, recreational fishing, and swimming) include restrictions of access to marine areas used for aquaculture, the visual impacts of aquaculture farms (e.g. mooring structures at the surface), and the undesirable effects on the marine environment and/or wildlife. Alternatively, the tourism sector can benefit from aquaculture activities where farms become a wildlife hot spot (e.g. through attracting birds or marine mammals) for recreational users and by providing high quality seafood products.

Human-induced eutrophication may cause reduced water quality with ensuing adverse impacts on aquaculture activities (e.g. presence of toxic algae blooms and reduced oxygen concentrations affecting growth). Some aquaculture sectors such as seaweed and shellfish may help bio-remediate the effects of eutrophication.

Aquaculture activities may interact with the MPA designation process and affect the achievability of MPA conservation objectives. However, certain aquaculture activities such as mussel farms may enhance fishery resources nearby the farms as well as retaining benthic habitat function within the farm, thereby potentially retaining MPA objectives.

Future projections and emerging threats and opportunities

Sustainable aquaculture is a vital part of a future solution for global and regional food security and nutrition, as well as in terms of contribution to the socio-economic development of rural areas. Sustainable aquaculture development should consider diversifying the industry, the potential impacts of climate change, and any interactions with other existing and emerging human activities affecting the marine environment. Table 2 summarizes information needs to support the aquaculture in the Celtic Seas ecoregion.

Diversifying the industry

Current innovations in finfish culture diversification include land-based production of halibut in Scotland and cleaner fish in Wales, while attempts with several other finfish species (sea bass, turbot and Atlantic cod) in UK and Ireland have proven unsuccessful. Failure with these species has often been for economic reasons rather than technical feasibility. However, experience gained through these early innovations may inform future attempts at farming these species when the economic environment is more suitable. Diversification in other ICES areas may act as a template for UK and Ireland, for example, Atlantic cod as a candidate species is once again being developed in Norway. Aquaculture production of new marine finfish species is complicated and to be successful it requires the elaboration of breeding, disease control, and welfare programmes, in addition to the development of production methods that minimize environmental impacts.

Diversification may also relate to existing culture systems in the ecoregion in response to changing environmental or biological drivers. In addition to examining the feasibility of relocating salmon farms to more exposed offshore sites (see below), reductions of and alternatives to the use of chemical treatments should be considered. These alternatives should take into consideration associated animal welfare issues.

There is some competence and expertise available in the ecoregion for offshore aquaculture development. Planning of offshore farming (of salmon) may be informed in the Celtic Seas ecoregion by developments in the Norwegian Sea. Offshore farming has several advantages for salmon production in that it reduces sea lice, improves fish health, increases potential space and reduces competition with other stakeholders, and has greater public acceptance. However, securing good fish welfare can be a challenge and should be considered when planning new offshore salmon farms. Offshore shellfish aquaculture is considered to have a high level of technological readiness and could be considered an option in the ecoregion.

Seaweed aquaculture 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. Provided the market can be developed, there is potential for large-scale aquaculture production for seaweeds in the ecoregion, including the development of offshore sites.

Integrated multitrophic aquaculture (IMTA) is the culture of species from different trophic levels, including extractive species that utilize nutrients and particulates from the fed species. A primary aim of IMTA is to minimize the environmental impact, increase, and promote a circular economy business model. Small-scale pilot studies have been carried out in several locations in the ecoregion as well as beyond the Celtic Seas in offshore areas. In general, integrated multitrophic aquaculture has been found to be more socially acceptable and may be relevant when developing new forms of aquaculture.

Impacts of climate change

Climate change is likely to be a primary driver for change in the aquaculture industry in the ecoregion in the coming decades. Climate change can hamper sustainable growth and existing capacity for aquaculture and alter interactions with other sectors. It is expected to affect growth rates for most species farmed due to elevated temperatures, increase the risk of finfish escapees and mortalities as a result of extreme weather conditions, reduce the productivity of mussel aquaculture as a result of warming, change the risk level of shellfish accumulation of toxins from harmful algal blooms (HABs), and increase problems associated with some diseases and parasites, notably sea lice and gill disease. At the same time, climate change also offers opportunities for the development of new species for aquaculture and benefits for some shellfish species from increasing food availability. Consideration should be given to future temperature and hydrodynamic forecasts in area planning as well as exploring breeding and rearing technologies/systems together with identification of new cultured taxa in order to meet future challenges induced by climate change.

Integration of different sectors

The future growth of the aquaculture industry in the ecoregion will require more space, likely cause increased pressure on the marine ecosystem, and elevate interactions between different human activities, including commercial fisheries, shipping, tourism, designation of MPAs, and offshore renewable energy developments. Future developments will need to consider and apply an integrated approach to assessing synergies and trade-offs among sectors while investigating consequences across environmental, ecological, and socio-economic dimensions.

One of the particular areas of interest for growth in the ecoregion is the offshore wind energy industry. Co-location of aquaculture activities with offshore renewables can have socio-economic benefits in terms of earning capacity and costs for employees, families, and suppliers of both industries, with indirect impacts on consumers and the broader economy. Growth of aquaculture and renewable energy could also lead to both having competing interests for marine space. Aquaculture and offshore renewables can share common use of forecast and early warning systems, accommodation platforms, and potentially also staff. Reduction in wave attenuation as a result of the 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.

Table 2 Summary of main knowledge gaps and data needs regarding aquaculture within the Celtic Seas ecoregion.

Topic	Knowledge gaps and data needs
Description and location of aquaculture activities and practices	• high-level evidence of marine aquaculture, as information is either missing or not fully represented by either country or taxon • information on size of the aquaculture farms in different jurisdictions
Production over time	• production statistics from single jurisdictions with multiple ecoregions • better reporting of data from industry surveys • rearing technologies for high value seaweed species
Ecosystem/environment interactions	• information on the impact of sea lice from aquaculture on wild salmon • risk assessments on change in occurrence of diseases and pathogens • salmon escapement and the extent of genetic introgression of wild salmon • interactions between shellfish culture/salmon farms and marine mammals • impact of shellfish culture on biodiversity • consideration of habitat vulnerability and sensitivity in defining shellfish culture impacts • environmental interactions of seaweed culture • interactions of aquaculture and eutrophication • interactions with algal blooms and red tides • discharge amounts of chemicals/nutrients and chemotherapeutants • statistics in use of wild-caught cleaner fish • quantification of population-level effects of shellfish aquaculture on shorebirds • effects of plastic pollution caused by shellfish farming
Social and economic context	• general information and knowledge of socio-economic impacts of aquaculture activities
Interaction of environmental, economic, and social drivers	• socio-economic impacts of co-location of offshore renewables and aquaculture • interactions between farms and the surrounding environment or other activities (particularly for emerging forms of aquaculture and emerging industries)
Future projections and emerging threats and opportunities	• interactions and fluctuations of climate change and ocean acidification on growth and survival of cultured species • capacity of different species to adapt to climate change and offshore conditions • interactions with existing and emerging sectors • development of seaweed culture technologies • scaling and management of integrated multitrophic aquaculture • impacts of climate change and other factors on the dynamics of different pathogens and parasites • climate change impacts on fish and shellfish production systems

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Annex

Table A1 Common and scientific names of species

Common name	Scientific name
Abalones	*Haliotis discus hannai*
Asian shore crab	*Hemigrapsus sanguineus*
Atlantic cod	*Gadus morhua*
Atlantic Halibut	*Hippoglossus hippoglossus*
Atlantic salmon	*Salmo salar*
Badderlocks/Dabberlocks	*Alaria esculenta*
Ballan wrasse	*Labrus bergylta*
Brown trout	*Salmo trutta*
Chinese mitten crab	*Eriocheir sinensis*
Corkwing wrasse	*Symphodus melops*
Cuckoo wrasse	*Cuckoo wrasse*
Dulse/dillisk	*Palmaria palmata*
European sea bass	*Dicentrarchus labrax*
Goldsinny wrasse	*Ctenolabrus rupestris*
Haddock	*Melanogrammus aeglefinus*
Carpet sea squirt	*Didemnum vexillum*
King scallop	*Pecten maximus*
Leathery sea squirt	*Styela clava*
Lobster	*Homarus gammarus*
Lumpsucker/lumpfish	*Cyclopterus lumpus*
Manila clam/Japanese carpet shell	*Ruditapes philippinarum*
Mussel/*Mytilus* spp.	*Mytilus edulis, Mytilus galloprovincialis and hybrids*
European flat oyster	*Ostrea edulis*
Northern quahog	*Mercenaria mercenaria*
Pacific oyster	*Magallana gigas*
Queen scallop	*Aequipecten opercularis*
Rainbow trout	*Oncorhynchus mykiss*
Rock cook	*Centrolabrus exoletus*
Sea trout	*Salmo trutta trutta*
Seagrasses	*Zostera marina*
Slipper limpet	*Crepidula fornicata*
Stony sea urchin	*Paracentrotus lividus*
Sugar kelp	*Saccharina latissima*
Tangle kelp	*Laminaria digitata*
Turbot	*Scophthalmus maximus*