WORKSHOP ON THE FAROES ECOREGION AQUACULTURE OVERVIEW (WKFaroesAO)

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i Executive summary

The Workshop on the Faroes ecoregion Aquaculture Overview (WKFaroesAO) was established to assemble and synthesize data and information for the Faroes ecoregion aquaculture overview.

Marine aquaculture production within the ecoregion is dominated by Atlantic salmon farming, but seaweed farming is an emerging industry and there are plans to allocate sites for shellfish farming in the near future. Today three fish farming companies produce Atlantic salmon and two companies farm seaweed.

The dominance of salmon farming is also reflected in the aquaculture legislation. The aim of the Faroese legislation on aquaculture is to promote profitability and competitiveness in aqua-culture within a sustainable framework with regards to animal health. In the legislation there is great emphasis on biosecurity, environment, and salmon lice. Management of salmon lice is-sues at aquaculture sites has a direct impact on the production of allowed number of smolt.

Environmental licenses are required for all aquaculture activities. These impose conditions for operations, which are aimed at minimizing pollution from aquaculture production and the impact on the surrounding environment. Aquaculture practices may be ordered to adaptations and implement necessary measures in order to minimize pollution.

The authorities have an IT-system, where all operators are obligated to report fish health and welfare data once a week, such as number of fish, weight, feed use, use of chemicals, mortalities etc. Salmon lice on farmed fish are counted biweekly by a third party and reported via the IT-system no later than one day after counting.

Environmental threats of aquaculture include emissions of dissolved nutrients, particulate organic matter, pollutants, and chemicals. In general, knowledge is scarce on the potential far-field ecosystem effects from aquaculture. Coastal environmental monitoring is connected to monitoring of fish farming activity and there is a need for time-series in order to detect possible environmental changes due to aquaculture and other anthropogenic activities, including cli-mate change.

Since 2012, the aquaculture industry has experienced large profit rates and is now a well consolidated industry able to self-finance most of its investments. Today the aquaculture industry is one of the most important industries on the Faroe Islands, employing around 5 percent of the workforce and providing more than 25 percent of the income of the Faroese balance of payments. The aquaculture industry has large ripple effects on other industries and is a major contributor to the public revenue. There is generally a positive attitude towards the aquaculture industry, although there are some public concerns regarding pollution and interactions with wild fisheries.

One of the major developments in the aquaculture industry in recent years has been the large investments into on-land smolt farms to shorten the production time at sea to diminish salmon lice problems. Continuous efforts are also being made with closed systems and moving further offshore.

In future, aquaculture in the ecoregion is likely to diversify both regarding farming low trophic species and diversification in farming methods. There are significant uncertainties related to the effect of climate change on the sector. Evaluating the expected impacts of climate change on the Faroese aquaculture industry should therefore be prioritized and is a prerequisite to enabling the development of climate change adaptation plans for the sector.

ii Expert group information

Expert group name	Workshop on the Faroes ecoregion Aquaculture Overview (WKFaroesAO)
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chairs	Gunnvør á Nordi, Faroe Islands
	Henn Ojaveer, Denmark
Meeting venue and dates	31 May–2 June 2022, Tórshavn, Faroe Islands (12 participants)

1 Introduction

The Faroes ecoregion covers the Faroe Shelf and surrounding waters in the Faroe Islands Exclusive Economic Zone (Figure 1.1). It borders the Icelandic Waters, Norwegian Sea, Celtic Seas and the Oceanic Northeast Atlantic ecoregions.

This report summarises the regional and temporal information on aquaculture production in the Faroes ecoregion. It provides a broad insight into the practices and management of Faroese aquaculture and describes some of the environmental and socio-economic interactions of aquaculture. Future projections and emerging threats and opportunities in aquaculture are also considered.

Faroese aquaculture is dominated by salmon farming and farming practices are similar between the sites, with automatic feeding and camera monitoring of the fish. The farming occurs along the coast of the Faroe Islands. During recent years seaweed farming has steadily increased and in future, it is expected that aquaculture will be more diversified as licences for bivalve farming will be issued.

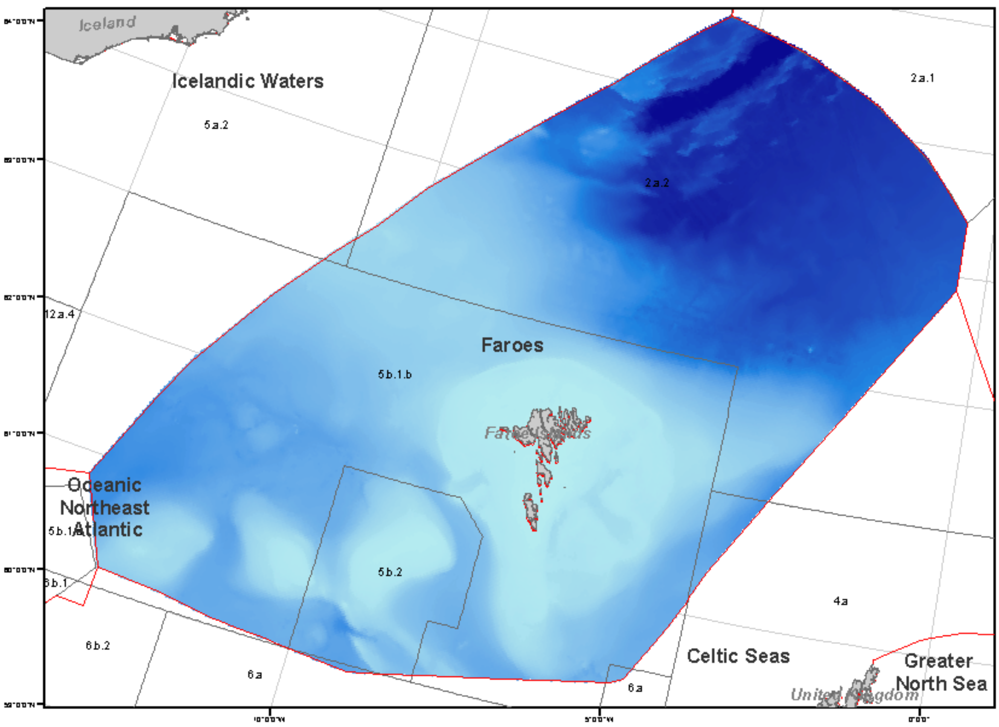

Figure 1.1 The Faroes ecoregion as defined by ICES.

1.1 Bathymetry and hydrography

The Faroe Islands are located on the Greenland-Scotland Ridge. To the east, the Faroes ecoregion extends into the deepest passage across the ridge, the Faroe-Shetland Channel, to the west the Iceland-Faroe Ridge, and the Nordic Seas and the Atlantic Ocean to the north and south. Thus, the region is in the area where warm saline waters from the Atlantic flow northwards in the upper water masses while cold waters from the Arctic region flow south through deep channels (Erenbjerg *et al.*, 2020).

Centrally in the ecoregion is the Faroe Shelf. The Faroe Shelf water is separated from the oceanic water by the Faroe shelf front. Inside the front tidal mixing induces a high degree of homogeneity but further in the fjords, the water masses can be stratified.

The marine aquaculture operates inside the tidal front separating the open oceanic waters from the Faroe shelf water and thus emphasis will be on describing the central shelf and fjords in this report.

1.2 Central shelf

Hydrography

On the Faroe Shelf, there are strong tidal currents, efficiently mixing the central shelf water. This results in homogeneous water masses, without summer stratification in the central shelf areas (Gaard, 1996; Larsen *et al.*, 2009). This well-mixed shelf water is separated relatively well from the offshore water by a persistent tidal front at the 100–150 m bottom depth contour (Figure 1.2). The residual currents at the central shelf have a clockwise circulation around the islands with typical velocities around 10 cm s^{-1} (Larsen *et al.*, 2008).

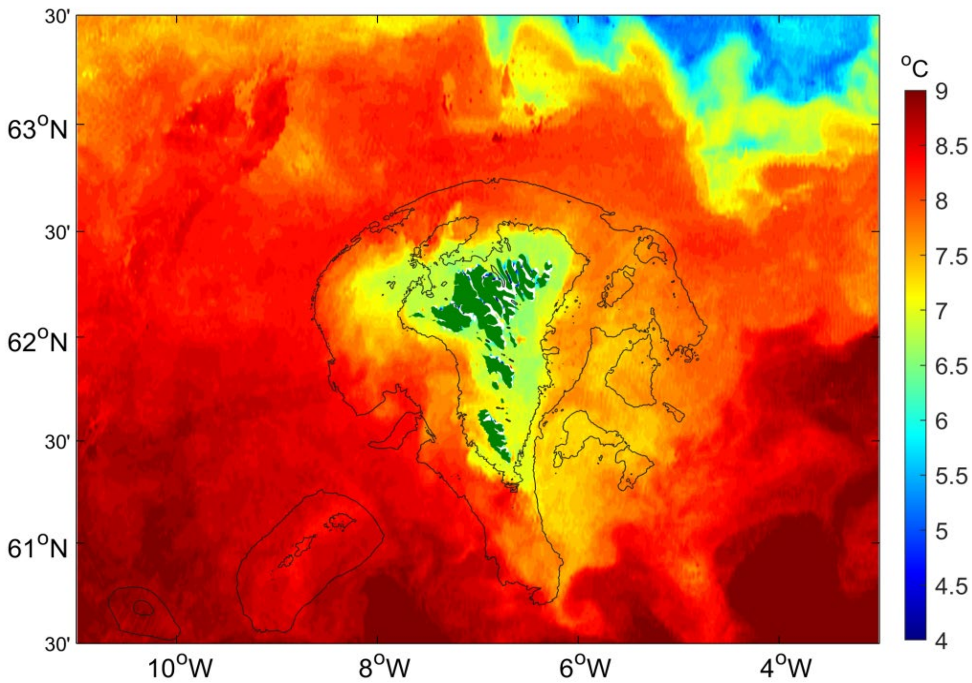

Figure 1.2 Sea surface temperature around the Faroe Islands on 21–22 April 2020 from infrared satellite imagery (Dataset compiled by Faroe Marine Research Institute, 2022).

The shelf-front provides a fair, although temporally variable separation between the central-shelf and outer-shelf water masses. The residence time is 1–2 months, but is likely highly variable (Larsen *et al.*, 2009; Rasmussen *et al.*, 2014; Eliasen *et al.*, 2016).

The temperature varies between ~6°C in March to ~11°C in September, and salinity varies between 35.0–35.2 and is usually 0.10–0.15 lower than the surrounding off-shelf water (Larsen *et al.*, 2008).

The retention of the central shelf water mass supports a neritic ecosystem, with distinct planktonic communities, benthic fauna, and fish stocks. However, it also hinders products from the fish farms, such as sea lice larvae, to be advected from the shelf (Kragesteen *et al.*, 2018).

Phytoplankton

The environmental conditions for phytoplankton growth on the central shelf are quite different from conditions in fjords and the open ocean. The turbulent waters support a typical diatom-dominated plankton community and usually various large-sized diatom species dominate during spring and summer (Gaard, 1996; Debes *et al.*, 2008).

On average, the phytoplankton biomass increases in May and continues until August to September (Figure 1.3) and in a typical year the total annual primary production is about 200 g C m^{-2} (Debes *et al.*, 2008). However, there is large interannual variability of the timing of the onset of primary production which fluctuates between April and June, and the phytoplankton biomass is also variable between years. Chlorophyll *a* (Chl *a*) concentrations fluctuate between 0.5 and 14 µg chl *a* L^{-1} in spring and summer.

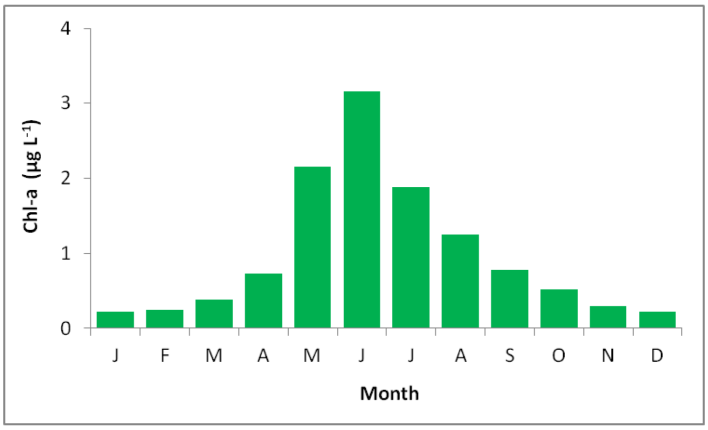

Figure 1.3 Monthly mean Chl *a* concentrations in mixed shelf waters from 1997–2021 (Faroe Marine Research Institute).

The drivers controlling the variable primary production in the central shelf water are not fully understood. However, variable exchange rate of the shelf water seems to postpone spring bloom and reduce the primary production (Eliasen *et al.*, 2005; 2016).

Due to the retention of the water on the central shelf, its nutrient pool is limited and in periods with high primary production, the nutrient concentrations may reduce to low levels (Figure 1.4). During these circumstances, nutrients potentially alter the phytoplankton community, especially the growth of large-sized diatoms. In years with low primary production the nutrient concentrations remain relatively high during summer (e.g. Gaard, 2003; Hansen *et al.*, 2005; Eliasen *et al.*, 2016).

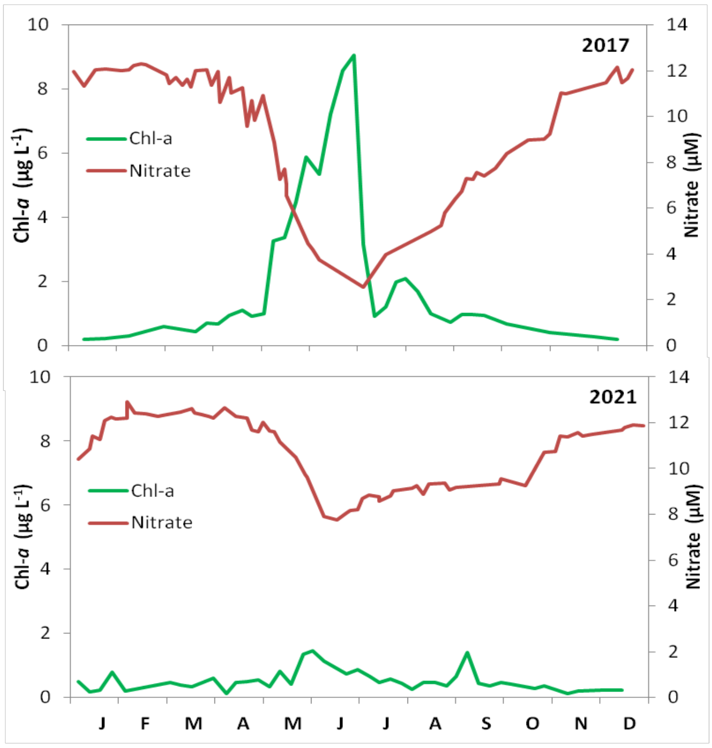

Figure 1.4 Chl *a* and nitrate concentrations in mixed shelf waters in 2017 with high Chl *a* and low nutrient concentrations and 2021, a year with very low Chl *a* and high nutrient concentrations (Faroe Marine Research Institute).

There is a clear positive relationship between primary production and higher trophic levels such as fish larval growth and abundance, fish recruitment and growth, shellfish and seabirds (Steingrund and Gaard, 2005; Gaard *et al.*, 2006; Bonitz *et al.*, 2018; Jacobsen *et al.*, 2019).

Zooplankton

The zooplankton species composition on the central shelf also differs from that in the surrounding oceanic environment. While the zooplankton outside the tidal front is dominated by the copepod *Calanus finmarchicus*, the shelf community is a mixture of neritic copepods (mainly *Acartia* spp. and *Temora longiremis*), oceanic species that originally are advected onto the central shelf from the off-shelf water mass (mainly *C. finmarchicus*) and meroplanktonic larvae from benthic fauna on the shelf (Gaard, 1999; Debes and Eliasen, 2006; Jacobsen *et al.*, 2018). The seasonal fluctuations follow those of phytoplankton, and the copepod egg production rates are clearly dependent on phytoplankton abundance (Gaard, 2000; Debes and Eliasen 2006, Jacobsen *et al.*, 2019). Thus, there is a clear bottom-up effect from phytoplankton to zooplankton in spring. However, in summer there is an interannual negative relationship between zooplankton and fish larvae and pelagic juveniles, indicating a top-down effect, from predating fish on zooplankton (Jacobsen *et al.*, 2019).

Fish

The Faroe shelf is a habitat for several local fish stocks. The most abundant species are cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), sandeel (*Ammodytes* spp.), and Norway pout (*Trisopterus esmarkii*). The main spawning season is between February and May. The eggs and larvae are advected clockwise and dispersed by the currents around the shelf area while they feed on zooplankton during spring and summer (Gaard and Steingrund, 2001; Gaard and Reinert, 2002; Jacobsen *et al.*, 2019; 2020).

When the larvae are about 3–4 months old, the pelagic phase of most juveniles is over. E.g., saithe and cod migrate into the fjords, sounds, and other shallow areas, while haddock, Norway pout, sandeel and other species make the transition to a predominant demersal habit on the plateau and the banks. For saithe this occurs in May and for the other three species in July. From an age of about 2 years, the cod mostly inhabit the shelf. The saithe move to the slope at the age of about 3 years.

Recruitment and abundance of cod and sandeel have generally been low during the last decades. Since the early 1990s the cod recruitment has been increasingly variable, generally with increasingly frequent low-recruitment years. Sandeel has undergone a long-lasting decreasing trend since the 1960ies with increasing frequency of years with poor recruitment. Sandeel has large effects on the several fish and seabird species that depend on it as a valuable food source (Gaard *et al*., 2002; ICES, 2021).

Other local species, such as haddock, Norway pout, whiting (*Merlangus merlangus*) and monkfish (*Lophius* sp.) show variability without a similar decreasing trend as cod and sandeel.

The reason behind the observed variability in recruitment, seems to be the high fishing mortality, causing foodweb instability between food production and food demand (ICES, 2022).

Seabed

The strong tidal currents on the Faroe Shelf cause resuspension of sediment materials and prevent the smallest particles from settling. In general, this results in large seabed particles in the shallowest areas where the tidal currents are strongest and gradually smaller particles in deeper areas (Figure 1.5).

Regarding waste particles from fish farms in exposed areas, tidal currents and waves also cause dispersion of faecal and food pellets, limiting accumulation of waste at the seabed below the fish cages (á Norði and Patursson, 2012).

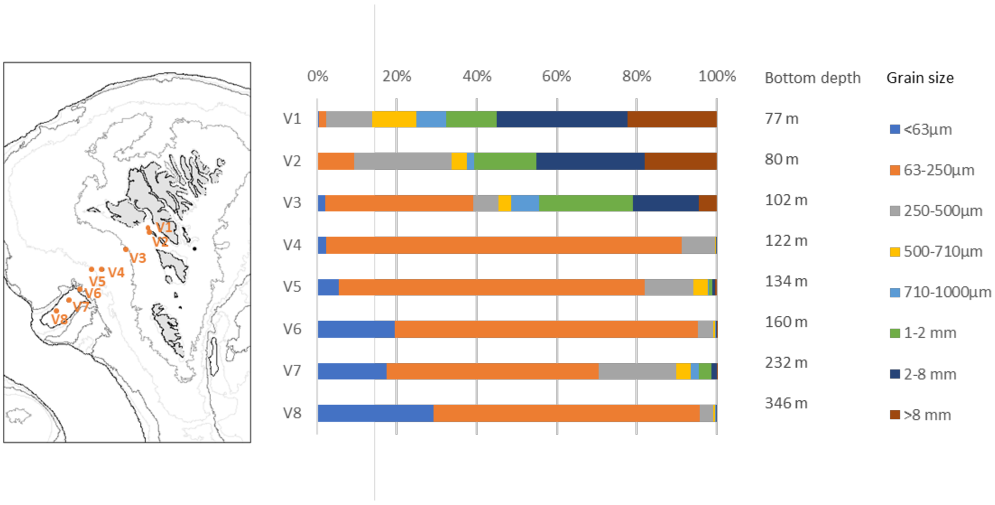

Figure 1.5 Sediment grain size distribution at a transect extending from the central Faroe Shelf in a southwest direction. (Redrawn from á Norði *et al.*, 2013).

1.3 Fjords and straits

Hydrography

The Faroe Islands are an archipelago containing multiple fjords with complicated coastlines. The sea around the islands is relatively warm and saline with stable conditions (Kragesteen *et al.*, 2018). Inside the fjords, the salinity above the halocline may reduce towards 34‰ during periods with high precipitation and freshwater run-off (á Norði *et al.*, 2011; Østerø *et al.*, 2022), compared to the 35.0-35.2 on the shelf (Larsen *et al.*, 2008).

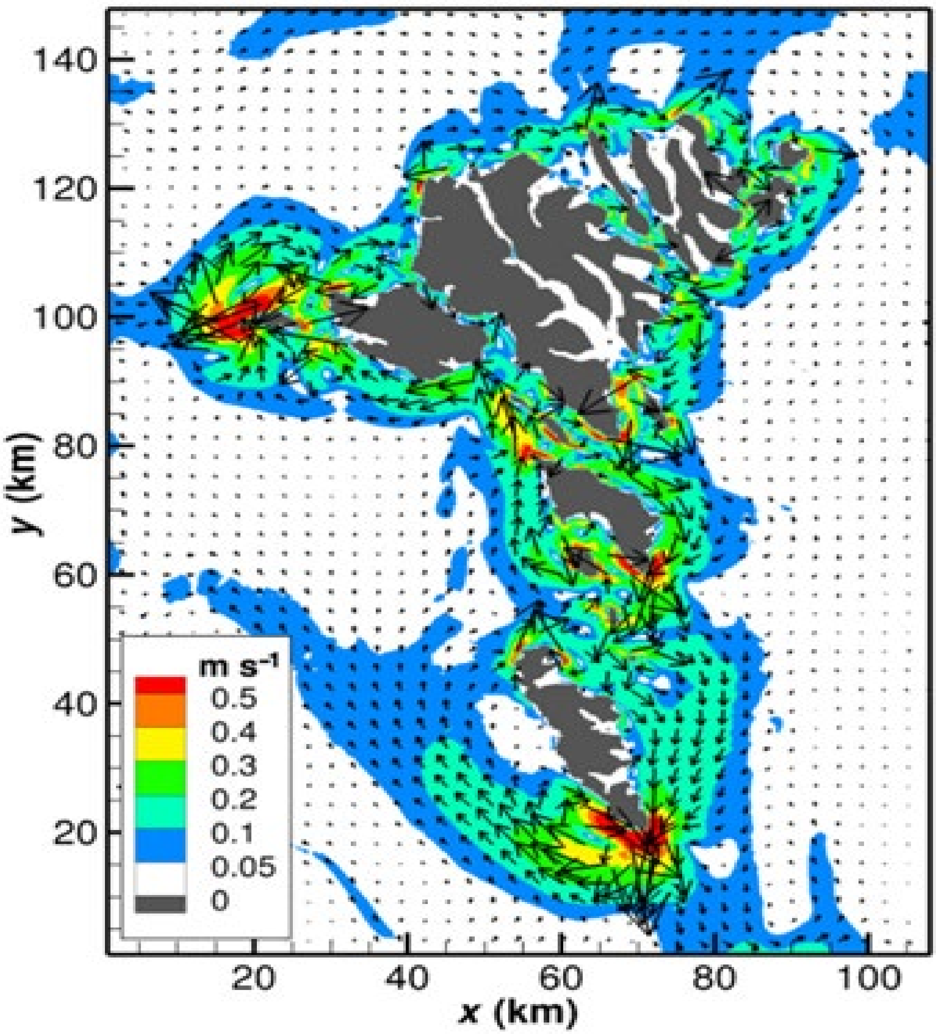

Figure 1.6 Residual tidal current velocity around the Faroe Islands (Kragesteen *et al.*, 2018).

In most straits, the tidal currents are strong and water masses are mixed throughout the water column, while tidal currents are considerably weaker in most fjords (Figure 1.6). In fjords, the water masses are typically stratified and the circulation is estuarine and wind-driven with influence from the Coriolis force (Figure 1.7). The stratification is, however, quite weak with vertical density differences less than 1 PSU and temperature differences less than 3°C and is frequently interrupted by winds (Figure 1.8). During winter, stratification is caused by freshwater and in summer heating of the surface water adds to the stratification (Hansen *et al.*, 1990; Østerø *et al.*, 2022).

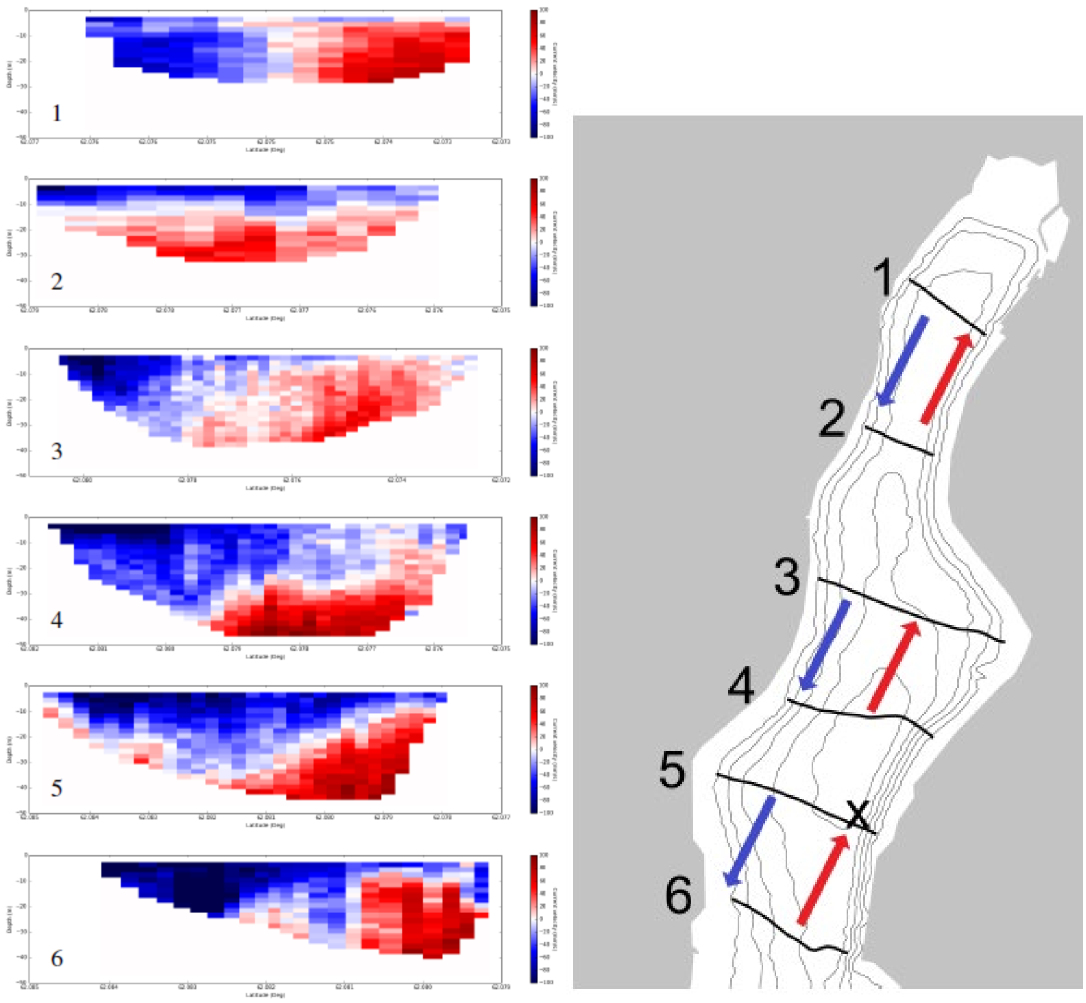

Figure 1.7 Current velocities in direction of the fjord showing a situation with estuarine circulation influenced by the Coriolis force in the fjord Sørvágsfjørður (á Norði and Patursson, 2017).

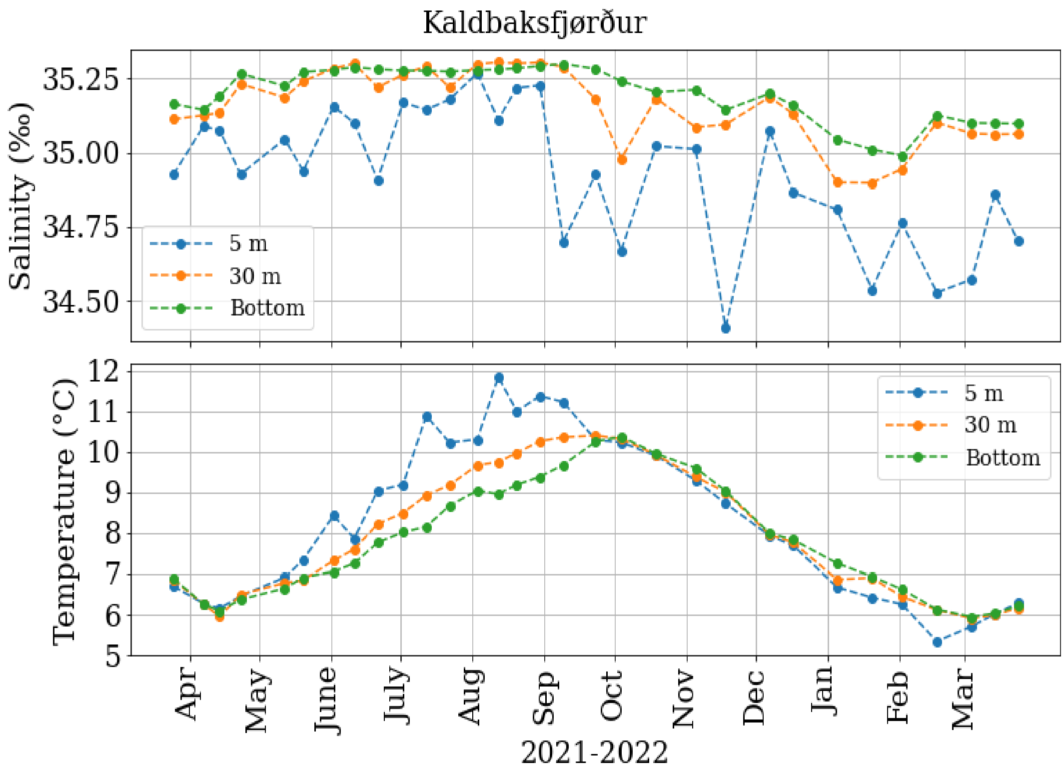

Fig 1.8 Seasonal temperature and salinity variations at three depths in a fjord dominated by estuarine circulation (Station KA09 in Østerø *et al.*, 2022).

At the entrance of some fjords there are sills that cause isolation of the bottom water during summer (Hansen *et al.*, 1990, Hansen, 2000). In the two fjords with the shallowest sills, compared to the bottom depth in the fjord, the bottom water is isolated during the entire summer with steadily declining oxygen concentrations (Hansen, 2000). Some fjords have deeper sills, only causing parts of the fjord to be isolated at various times during summer. In those cases, the oxygen concentrations may decline fast, and isolation is highly dependent on weather conditions (Østerø *et al.*, 2022).

Primary production and nutrients

Variations in phytoplankton concentrations in the fjords are driven by seasonal variations in sunlight and nutrient availability. During winter, the sunlight is scarce and phytoplankton concentrations low. The phytoplankton productive season is from late March to October. It is controlled by irradiance and commences as soon as the critical depth extends below the halocline (Figure 1.9).

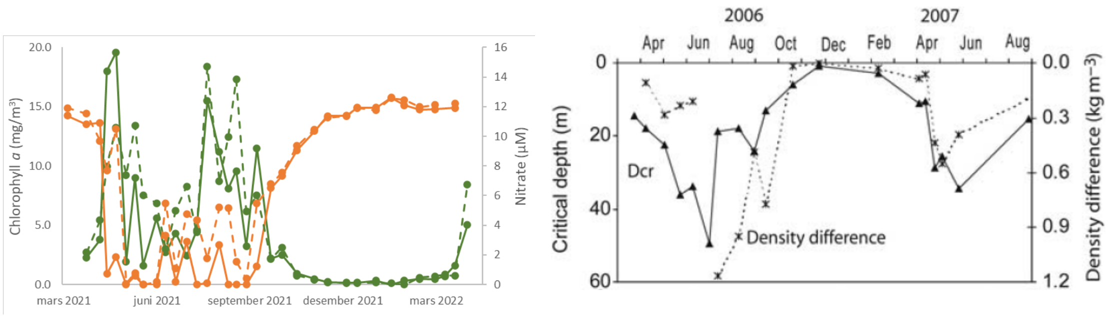

Figure 1.9 Concentrations of chl a (green) and nitrate (orange) at 4 m (solid line) and 12 m (stippled line) depth centrally in Kaldbaksfjrøður in 2021-2022 (Gaard *et al.*, 2011 and Østerø *et al.*, 2022).

After spring bloom primary production is controlled by nutrient limitations to a large extent. However, the weak stratification implies nutrient upwelling to the euphotic zone also during summer, sustaining a high annual primary production. The annual primary production as measured in two fjords is ~ 340 g C m^{-2} $year^{-1}$ (Vandkvalitetsinstituttet, 1987; Gaard *et al.*, 2011).

Fish farming is a primary source of anthropogenic nutrients to the fjords, and although this might influence the primary production, there is no long-term monitoring or modelling of the potential impact. The few measurements that can enlighten on potential eutrophication, do not show evident changes due to aquaculture.

The knowledge of harmful algae is scarce, as there is no national monitoring. All monitoring is conducted on request by fish farming companies and companies that export wild shellfish, and these data are not publicly available.

Mortality of farmed fish in relation to Harmful Algal Blooms are rare. Such mortalities have been observed in stratified fjords and straits, on five incidences since the onset of fish farming with the last two incidences occurring in 2006 and 2018. The algal species related to these mortalities were *Alexandrium tamarense*, *Heterosigma akashiwo* and *Chrysochromolina* (Eilif Gaard, personal communication).

Seabed

Around half of the organic carbon from the primary production settles to the seabed with highest sedimentation rates associated with spring bloom (á Norði *et al.*, 2018). The steep slopes of the fjord imply that the organic matter in the shallow areas is resuspended and focused towards the deeper areas of the fjords (á Norði *et al.*, 2018), thus the organic content of the seabed generally increases with depth (Mortensen *et al.*, 2020; 2021).

Compared to the relatively narrow temperature range in the area, seasonal variations in the seabed are quite high. During summer there is a high sedimentation of organic material and in some areas, there is stagnant bottom water, on the other hand the small fjords and the short distance to the open sea imply high resuspension rates of the sediments especially during winter (á Norði *et al.*, 2012; 2018).

Soft bottom macrofauna diversity indices at reference sites in the various Faroese fjords indicate that the macrofauna diversity resembles the diversity in Norwegian fjords and is lower than in neighbouring countries such as Denmark and the UK (Mortensen *et al.*, 2020).

Fish

It is a common statement that fjords are nursery areas for various fish species, including commercial fish stocks. However, the knowledge regarding behaviour, distribution and ecology is scarce. Two ongoing projects that aim to investigate the abundance of fry in the fjords have started in 2022, which will shed light on this in future.

There are no naturally wild salmon stocks in the Faroese fjords and rivers today. It is difficult to say if there has ever been wild salmon in Faroese rivers; some place names indicate that salmon has been there, however, the names might as well have been the result of sea trout mistaken for salmon or due to stray salmon caught in the area. For about 70 years a wild salmon stock from Iceland has been in the river, Leynará. In the 1940s an interest group (Sílaveiðufelagið) took the initiative to import salmon fry from Iceland and release them to the river. A broodstock farm has been built on land, making it possible to strip salmon returning from the ocean and to maintain the Icelandic salmon stock. Furthermore, there have been a few new imports of salmon eggs from Iceland and Norway.

Brown trout (*Salmo trutta*) inhabits most of the rivers and some lakes in the Faroe Islands. An original stock of arctic char (*Salvenius alpinus*) was at the lake Leynavatn and has since been moved to other lakes as well (Havbit við atlantshavslaksi, 2022). In 2017 observations of humpback salmon (*Oncorhynchus gorbuscha*) started to occur among local recreational anglers, and it has been observed in small numbers every second year since then (Eliasen and Johannesen, 2021).

1.4 Seabirds and marine mammals

The Faroe Islands are breeding ground for many seabird species, most of which are migratory birds. Many species nest in the steep cliffs along the shore. Common species, as listed from species that breed highest to lowest in the cliff side, are Atlantic puffin (*Fratercula artica grabae*), northern fulmar (*Fulmarus glacialis*), razorbill (*Alca torda*), common guillemot (*Uria aalge*), black-legged kittiwake (*Rissa tridactyla*), European shag (*Phalacrocorax aristotelis*) and black guillemot (*Cepphus grylle*) (Fossaa *et al.*, 2006). Arctic tern (*Sterna paradisaea*) is also highly common and breeds in several colonies around the islands. Common eider *(Somateria mollissima)* is also very common and is resident in the islands.

Species that have limited geographic distribution on the Faroe Islands are northern gannet (*Morus bassanus*), which only breeds in one small island and European storm petrel (*Hydrobates pelagicus*), which only breeds in islands where there are no rats (*Rattus spp*.). The island Nólsoy supports the largest breeding colony of the European storm petrel in Europe (BirdLife International, 2022).

The harbour porpoise (*Phocaena phocaena*) and grey seal (*Halichoerus grypus*) are common close to the shore year-round. Other common marine mammal species in the ecoregion are pilot whale (*Globicephala melas*), Atlantic white sided dolphin (*Lagenorhynchus acutus*), Atlantic bottlenose dolphin (*Tursiops truncatus*), Northern bottlenose whale (*Hyperoodon ampullatus*), Minke whale (*Balaenoptera acutorostrata*), sperm whale (*Physeter macrocephalus*) and fin whale (*Balaenoptera physalus*) (Mikkelsen, Faroe Marine Research Institute, personal communication). Several other species have been observed and altogether 20% of the world's marine mammals have been observed in the ecoregion (Fossaa *et al.*, 2006).

Interactions between seabirds and aquaculture are mostly birds entanglement in bird nets and in some areas seals, that prey on farmed fish is an issue.

2 Description and location of marine aquaculture activities and practices

In many aspects, the conditions for salmon farming at sea are ideal on the Faroe Islands. The water temperature is stable and water quality high as there is a good dispersion of effluents. On the other hand, there are challenges with harsh weather conditions and limited farming areas.

Historically, salmon was not the species of interest in Faroese aquaculture. In 1887 and 1888 the potential for rainbow trout (*Oncorhynchus mykiss*) and oyster hatching for ocean ranching was discussed. In 1947 Føroya Sílaveiðifelag (the Faroese anglers association) started ocean ranging with brown trout and from 1949 to 1951 Atlantic salmon (*Salmo salar*) was included (Jacobsen, 2020).

The first pioneering attempts at hatching and farming rainbow trout in the Faroes were made in the 1950s, and pioneering attempts at hatching Atlantic salmon were conducted in the early 1970s. However, it was not until the 1980s, that we saw any significant production of farmed salmonids in coastal net cages (Jacobsen, 2020).

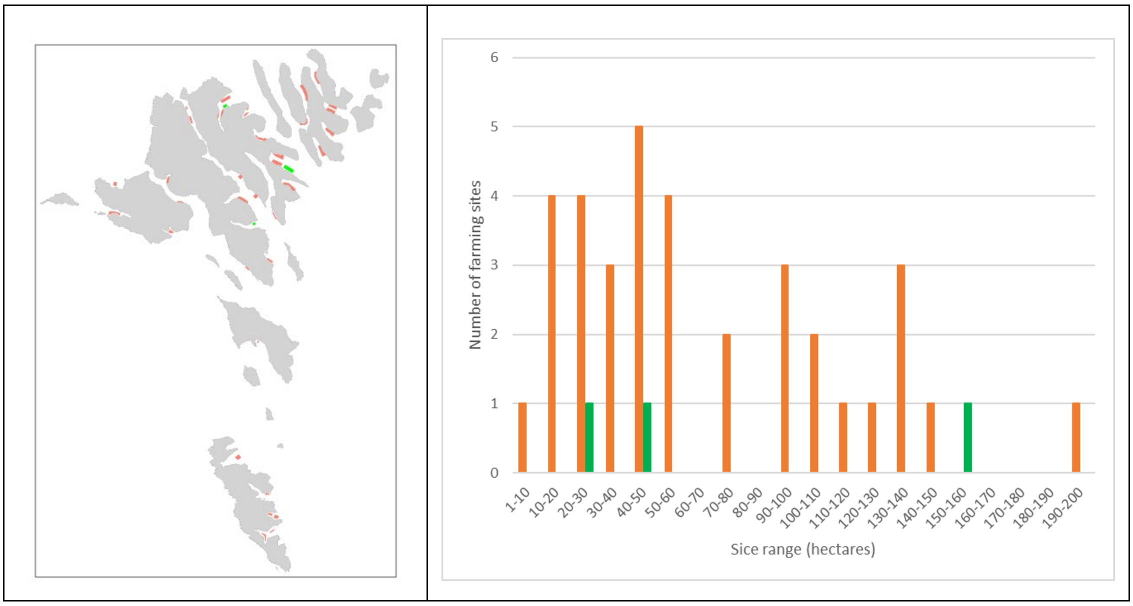

Figure 2.1 Location (left panel) and size (right panel) of marine areas allocated for Atlantic salmon farming (orange) and seaweed farming (green) (Redrawn from Landsverk Aling landsverk.fo).

To secure development in the villages, licences were issued primarily to operators, who had a connection close to the farming area and operations should be small scale (Jacobsen, 2020). In 1986 there were 65 farming areas run by approximately 50 companies (Jacobsen, 2020). The number of sites and operators has decreased substantially while the production at individual sites has increased. Farming areas have been gradually moved further out on the fjords where currents are stronger and internal infection with sea lice is lower.

Today 35 sites are allocated for Atlantic salmon farming and three sites are allocated to seaweed farming, and the areas are highly variable in size (Figure 2.1). There is no obvious relation between size of areas and exposure nor the production and size since permitted production is regulated by biological and environmental performance at the individual sites (see section 5).

The salmon farming sites are operated by three companies while two other companies farm seaweed. Not all the sites for salmon farming are active. Since 2019, 8 sites have not been in operation, most of which are sheltered locations. From 2019 to 2021 an average 21–25 sites were simultaneously in operation (Rúni Dam, Avrik, personal communication).

Seaweed farming started on trial basis in 2010 at sites allocated to salmon farms. The first two permanent sites for seaweed farming were allocated in 2020 and a third macrofauna farming site was allocated in 2021.The seaweed species produced are primarily *Saccharina latissima* and *Alaria esculenta*. The two seaweed production companies have quite different production strategies. One farms on submerged horizontal longlines which are receded every year, and the other company has developed a Macro Algae Cultivation Rig (MACR) with vertical seed lines connected to a horizontal main line. This company also uses a partial harvest method with regrowth of the macroalgae from the same holdfast, avoiding the need for reseeding after each harvest (Bak et al. 2018).

The salmon farming sites vary considerably in production of farmed fish. On average the biomass production during one farming cycle is around 6000 tonnes, but the variation in the lowest to highest production per site is considerable (Figure 2.2).

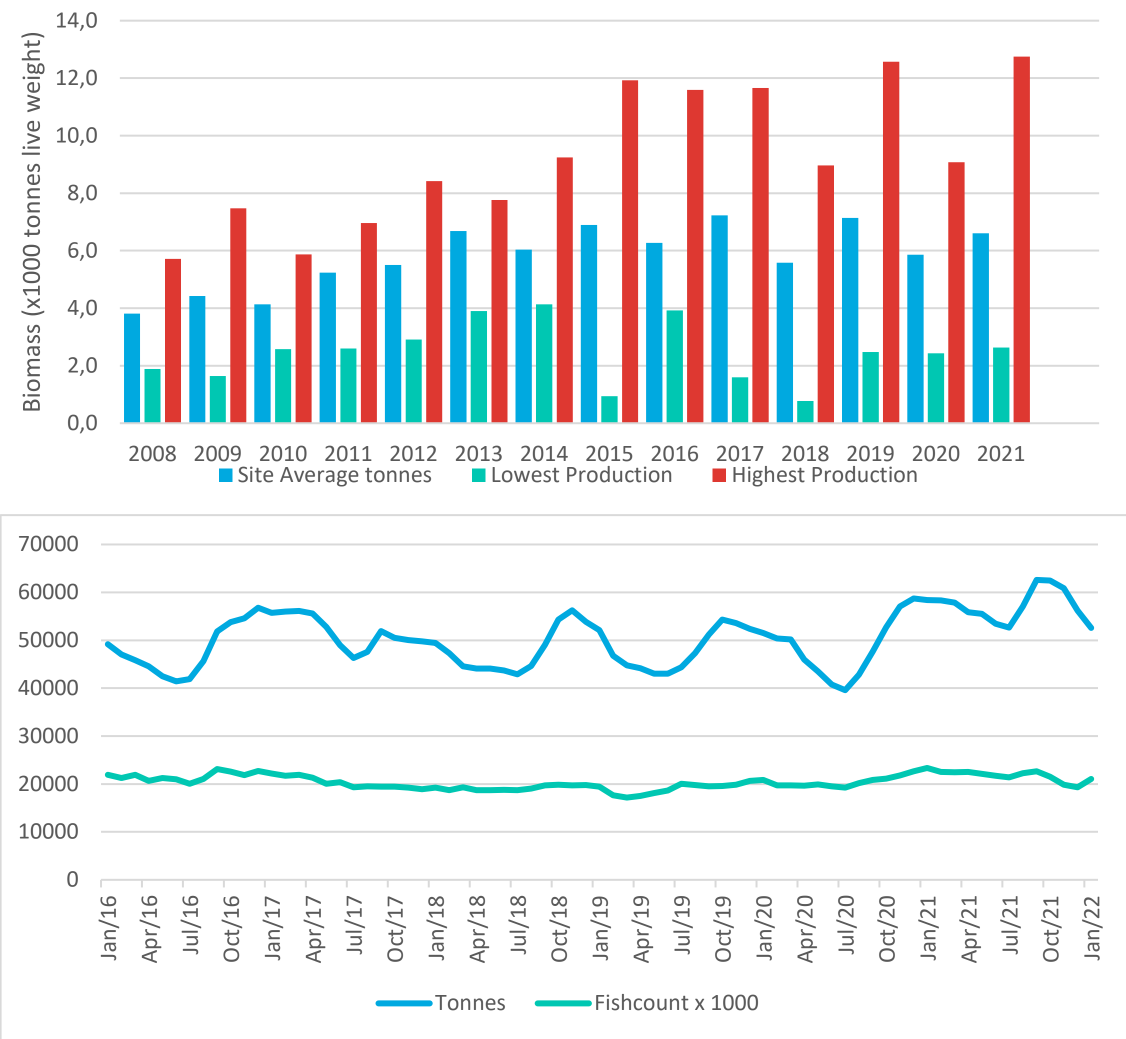

Figure 2.2 Upper figure, Biomass production per farming cycle at fish farming sites. Lower figure, standing biomass and total number of farmed fish at sea (Avrik).

The standing biomass and total number of farmed fish at sea have been fairly stable during the last 7 years (Figure 2.2), with total fish count at sea around 20,000,000 individuals while the standing biomass has varied between 40,000 and 62,000 tonnes, depending on the timing of the individual farming cycles.

The sites allocated for aquaculture are located along the coast (Figure 2.1) and conditions at the sites range from sheltered fjords with estuarine circulation and sills at the entrance (á Norði *et al*., 2011) to coastal sites exposed to ocean swells with measured significant wave heights (H_{m0}) up to 4 m (Abrahamsen and Patursson, 2017) or tidal currents up to 80 cm s^{-1} (Klebert *et al.*, 2015). Such exposed conditions are considered offshore, even though the distance to shore is quite short (Froehlich et al. 2017). The potential of farming further out on the Faroe shelf are currently being investigated.

The rough conditions at exposed sites sets high demand for gear, especially mooring systems, and although the gear essentially looks the same as in sheltered locations, with floating circular net pens, the gear is modified and tailored for the exact conditions at the sites (e.g. www.vonin.com/product/moorings).

The salmon farms at sea are supplied with smolts from eight smolt farms on land. Ova is imported from broodstocks in Norway and Iceland. Ova were produced in the Faroe Islands until 2017. From 2018 to 2021 all ova were imported. However, a work is going on with Faroese broodstock and in 2022 13% of the ova were domestically produced. The broodstock in the Faroe Islands, is maintained on land in freshwater and seawater facilities to minimize the risk of diseases. During the past years, there has been a development towards larger smolt size at transfer to the sea cages (Figure 2.3). This reduces the production time at sea (Figure 2.3), and the exposure to salmon lice and other diseases. The production at the farming sites can also potentially increase provided sufficient environmental conditions at the sites.

In 2021 the average weight of smolt at sea transfer was 425 g (Figure 2.3). This is considerably higher than in other salmon farming regions where the weight typically is below 200 g at transfer to sea (Nystøyl, 2022).

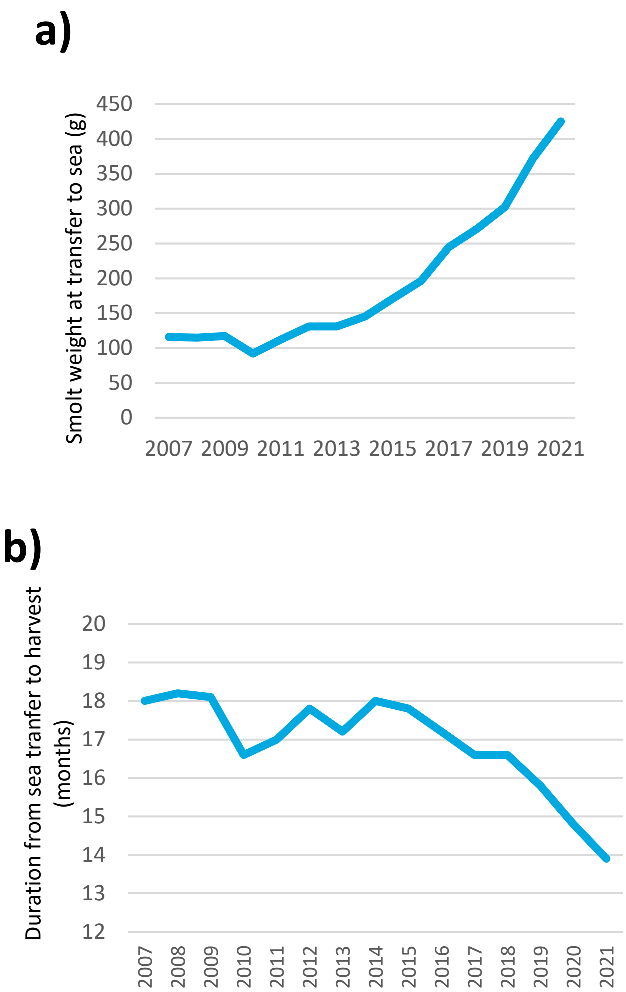

Figure 2.3 Average smolt weight at transfer to sea (a) and duration of the production cycle at sea (b).

The only difference in performance at sea by smolt that are large at transfer to sea compared to small smolt is the shorter duration of the farming cycle at sea. This was also the purpose of increasing the smolt size. The large smolt also show better growth performance (Table 2.1).

Table 2.1 Average growth, feeding activity and mortality of Atlantic salmon at sea grouped by smolt size at seatransfer.

Sea KPI's by smoltsize

Units harvested 2006-2021

All data

Size Group	Smolts gr	Harvest kg lw	FCR bio	FCR Eco	Morts % of count	Growth TGC	Vekst gr/dag	Temp °C	Seatime Months
S: u/100 gr	80	6,04	1,144	1,172	8,91	3,026	10,7	8,2	18,3
M: 100-200 gr	134	6,15	1,135	1,184	10,09	3,019	11,4	8,3	17,3
L: 200-500 gr	284	6,09	1,111	1,183	12,09	3,112	12,9	8,4	14,8
XL: +500 gr	679	5,84	1,074	1,116	9,12	3,424	15,4	8,0	11,1

Cleaner fish are commonly used as biological control of sea lice in the salmon farming industry. In 2014 when the first cleaner fish were imported, there was a concern of importing non-native species that might disturb the ecosystem. The wrasse species of interest at that time are non-native to Faroe Islands, which limits the species to lumpfish (*Cyclopterus lumpus*). Lumpfish were introduced to the salmon aquaculture in 2014 and in 2018 approximately half of the farming sites used lumpfish (Eliasen *et al.*, 2018). Lumpfish for use in the salmon farming industry are imported from Iceland and Wales and there is also some production in the Faroe Islands. The cleaner fish mostly origins form wild-caught fish that is stripped at on land facilities where the roes are hatched and the fish is grown to the desirable size.

3 Production over time

Production and export of farmed salmonids started to expand in the 1980s. Until 2010 both rainbow trout and Atlantic salmon were farmed on the Faroe Islands and since then, the aquaculture in the Faroes ecoregion has been totally dominated by Atlantic salmon. The reason for the cease of Rainbow trout farming was the lower profitability compared to Atlantic salmon. The market price for Rainbow trout was lower, the feed conversion rate higher and there were larger issues of downgrading in quality due to sexual maturation at sea. Farming of other fish species such as cod, halibut and lumpfish have been tested, but the species have to a very little extent been farmed at commercial scale (Jacobsen, 2020).

Production of salmonids gradually increased during the 1980s, but various diseases, sea lice and financial instability resulted in many bankruptcies, and farming licences were either annulled or combined (Jacobsen, 2011) and in the early 1990s production decreased (Figure 3.1). Afterwards there was a period with increasing production but in the early 2000s outbreaks of Infectious Salmon Anaemia (ISA) occurred at most of the fish farms. At the same time sales prices decreased substantially and financial providers were reluctant to finance restocking due to the high risk. Thus, the production plummeted from 59000 tonnes in 2003 to 15200 tonnes in 2006 (Figure 3.1). The framework for aquaculture in the Faroe Islands was revised and reconstructed from scratch as a collaboration between the Food and Veterinary Authority, financial institutions, and the Faroese Fish Farmers Association (Jacobsen, 2011). The most revolutionary change was that only one year class was allowed at each farming site with mandatory fallowing between year classes. Detailed regulations to the daily operations at the fish farms to prevent disease transfer were formulated. e.g. monitoring for diseases and daily collection of dead fish with immediate silage. Stricter regulations in the case of disease outbreaks were also formulated (Jacobsen, 2011).

Since the reform salmon production has steadily increased and in 2021 the production was over 95 thousand tonnes in gutted weight (Figure 3.1).

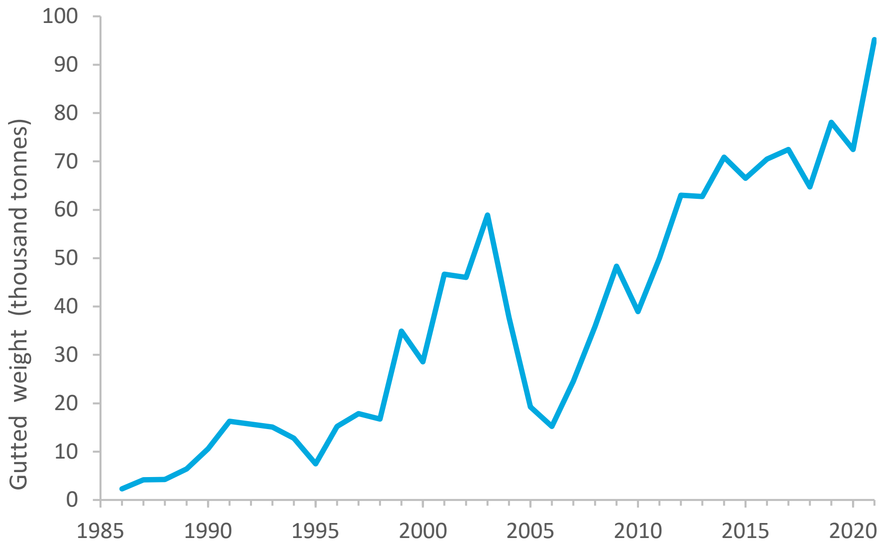

Figure 3.1 Harvest of Atlantic salmon in the Faroes ecoregion from 1986 to 2021 (Avrik).

During recent years, aquaculture in the Faroes ecoregion has started to diversify as seaweed farming is steadily increasing. In 2021 the total harvest of farmed seaweed was 160 tonnes in wet weight (Figure 3.2.

Most of the biomass is exported to European markets as food, food ingredients and feed additives for livestock. There is also some production for the local food market, and in addition sewed is produced for Lumpfish shelters in salmon farms, AkvaNest.

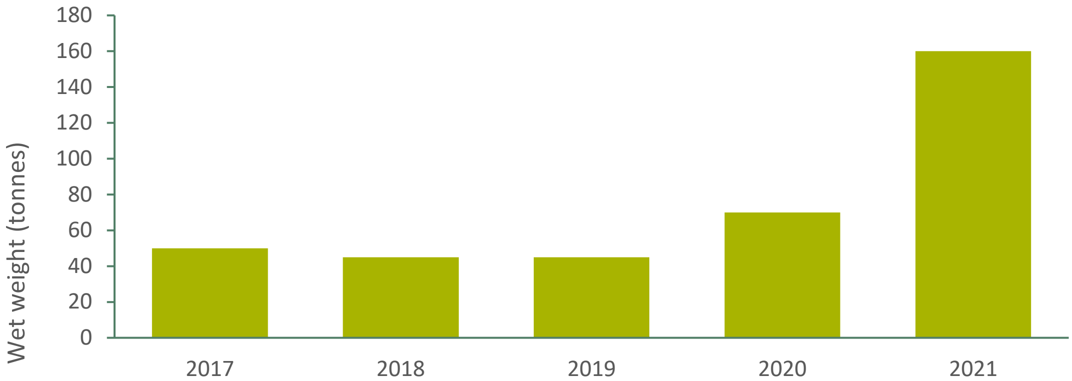

Figure 3.2 Harvest of farmed seaweed in the Faroes ecoregion. Source: the Faroese Fish Farmers Association annual statements.

3.1 Performance measures of salmon farming over time

The conversion of feed into biomass can be regarded as a measure of effectivity in the salmon aquaculture. Multiple factors affect the feed conversion ratio, including the feed quality and the feeding effectiveness, but also environmental factors that affect the fish health and survival. The reform of the aquaculture industry in the 2000s had a remarkable impact on the feed conversion ratio (Figure 3.3). Towards the ISA crises in the early 2000s the feed conversion factor steadily increased, but after the crises it dropped markedly and from 2006 to 2016 it was constantly below 1.2. After the introduction of mechanical and thermal sea lice treatments the economic feed conversion ratio increased, while the biological feed conversion rate decreased, the increasing difference between FCReco and FCRbio reflects the increasing biomass loss before harvest (Figure 3.3).

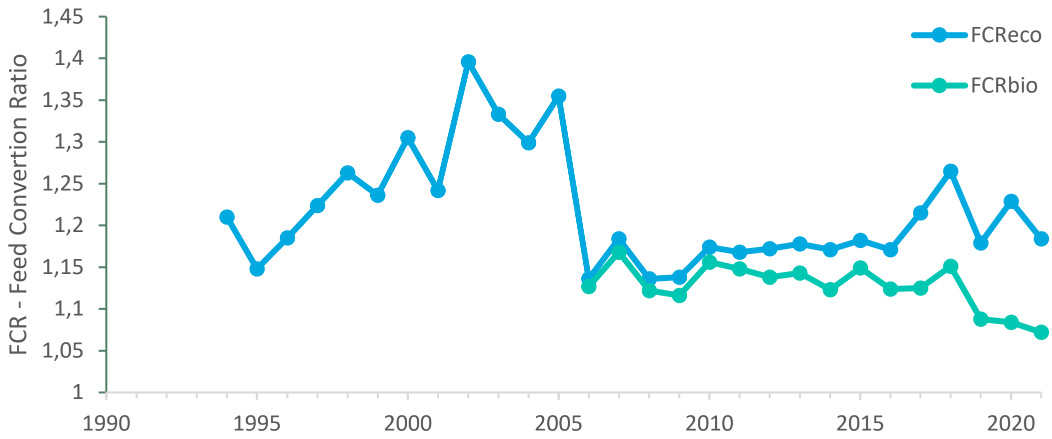

Figure 3.3 Economic and biological Feed Conversion Ratio (FCR) for the Faroese ecoregion. FCR is the ratio of feed used vs. biomass produced. The difference between FCReco and FCRbio is that fish that die before harvest are included in FCRbio while FCReco only includes harvested biomass (Avrik).

The major reform of the industry in the 2000s had a significant effect on the biological performance of coastal fish farming (Figure 3.4). The mortality decreased from 28% in 2002 to 3% in 2005, and for several years the Faroes ecoregion had the lowest mortality rate compared to the other salmon producing countries (Nystøyl, 2022). The mortality rate has however gradually increased again with the introduction of mechanical and thermal lice treatments and due to farming in more exposed areas. According to Nystøyl (2022) the mortality in Faroe Islands was between 5 and 10% from 2010 to 2014, while it was around 20% in Norway and Chile, and even higher in UK. But from 2016 to 2020, the mortality in Norway and the Faroe Islands was between 15 and 20% in both countries. Mortalities in Chile have been quite fluctuating. In 2015 it was above 30% but from 2016 to 2019 it was somewhat lower than in Norway and Faroe Islands.

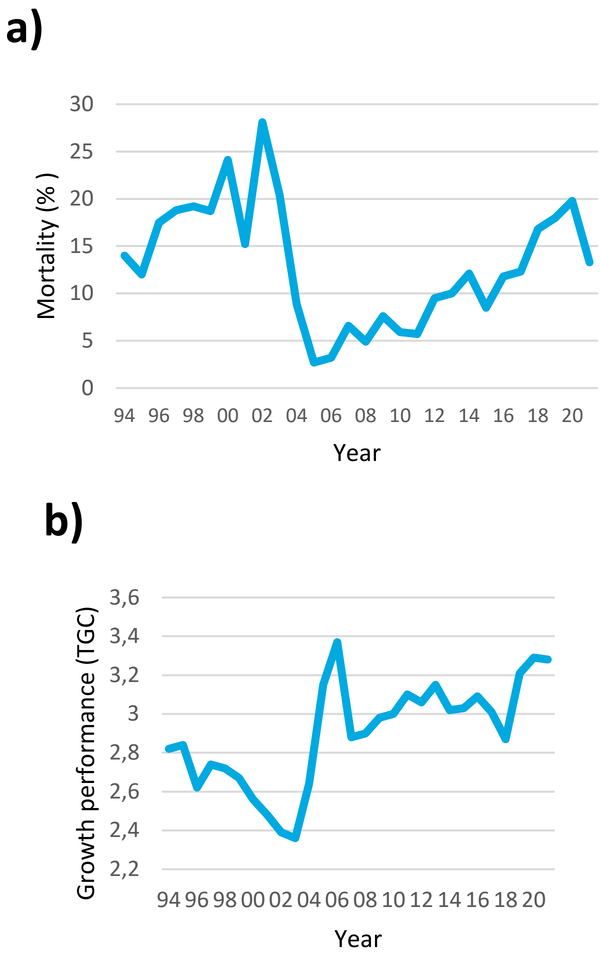

Figure 3.4 Mortality at sea as % of stocked salmon count (a), and Growth performance of salmon (b). Thermal growth coefficient (TGC) is a measure for fish growth, where the start weight, end weight and the temperature are considered. A score of 3.00 is considered average for salmon. 2.5 is poor and 3.5 is good (Avrik).

The highest average growth performance in the history of aquaculture in the Faroes ecoregion was just after the reform with a TGC of 3.37 in 2006. The years 2005 and 2006 were exceptional, since the production was historically low and due to lack of finances only a small part of the smolts produced on land were transferred to sea. Thus, there was an excessive selection towards high quality smolt. It was also in this period that salmon smolt were kept on land for 2 years for the first time in the farming history of the ecoregion. The TGC decreased a bit in the following years but since 2019 the average TGC for the ecoregion has constantly been above 3.2 (Figure 3.4 b).

4 Policy and legal foundation

The aim of the Faroese legislation on aquaculture is to promote profitability and competitiveness in aquaculture within a sustainable framework with regards to animal health. The primary legislations are:

- The aquaculture act (Aquaculture act, 2009), which is the general and coordinating law
- The animal welfare act (Animal welfare act, 2018)
- The animal diseases act (Animal diseases act, 2001) with the regulation on establishment and biosecurity of aquatic farms (Biosecurity regulation,2019) and the sea lice regulation (Sea lice regulation, 2016)
- The environmental protection act (Environmental protection act, 1988)
- The food act (Food act, 2010)

4.1 Licensing principles

A licence issued by the Food and Veterinary Authority (FFVA) is required in order to build, prepare, restructure, expand, buy, or operate a site intended for the rearing of fish. Licences for aquaculture sites are only issued after the application has been reviewed by several other institutions to ensure that they meet the requirements of the Environmental Protection Act, the Animal Diseases Act and the Food Act and that the decision does not conflict with other interests in the area, such as urban planning, nature conservation or other plans for the area. Licences for aquaculture ensure responsible working conditions and the required high standards for animal welfare and hygiene. Licences are transferable, issued for 12 years with possibility for renewal.

For commercial aquaculture there is an upper limit for ownership, as each company cannot own more than 50% of the total commercial licences for salmon farming at sea. The licences do not have an upper limit for production. Upper limits are controlled when FFVA and Faroese Environment Agency (FEA) each in their separate ways approve production plans for each new generation of fish regarding fish health, welfare and environment. This arrangement opens for increased production at sites with good fish health and welfare and low impact on the environment. FFVA sets upper limits from sea lice counts as described in 5.1.2 as well as from other health and welfare parameters such as mortality rate. When assessing approvals of production plans the FEA looks at a variety of factors and approvals are based on an individual estimate in each case. For example, the results of seabed surveys, production- and feed amount in the previous cycles is considered, as well as any new or changed operational measures.

Furthermore, from 2012 it is not possible for non-Faroese companies or persons to own more than 20% of the commercial licences (Aquaculture act amendment, 2012). Companies who had licences prior to 2012 were allowed to keep them. This limitation only applies to salmon farming at sea, which allows non-Faroese persons or companies to operate in all other aquaculture production, for example land-based farming, offshore farming, shellfish and seaweed farming.

Licencing processes

For new licenses the FFVA must first determine which fjords and aquaculture species will be offered in a licensing round. Then there is a licensing round with information on which fjords and species there can be applied for. The applicants must hand the application in on the application form, that is made for the licensing round. Included in the application there has to be a map, showing the exact limited area for the planned activity.

When the application is received, it is sent for consultation to relevant public authorities, municipalities and other parties involved.

After the consultation, the in-house processing of the applications according to the legislation contains that approval must be granted by the FEA, the Faroese Veterinary Authority and the Faroese Food Authority.

Other Considerations are:

- The applicant´s interests
- Possible conflicts of interest, regarding:
    - Use of the area
    - Other aquaculture activity
    - Conservation area
    - City plans
    - Governmental plans for activity on the fiords

Depending on the demanded granted approvals and reading of the issue in general, a licence can be approved for a maximum of 12 years with possibility for renewal.

Specified in a licence is species, biological stage (broodstock, smolt, fish), water/sea, location (cadastral number or ocean coordinates) license and validity period. Note that no quantity and/or biomass is in the license, as this is processed in the operation plans (See section 5).

As the license term draws to an end, the licensee can apply for a renewal of the given license. The process for applications for renewal of licenses is similar to the process of applications for new licences, except that there is no need for a licensing round.

During the license validity period the licensee can apply for changes in the license regarding the location.

Major issues during the licensing process the last 10 years have mainly been conflicts of interest regarding the applicant's need for the applied location vs. other use of the area such as lobsterfishing. Other issues have arisen the past years in connection with the relocation of breeding sites. For the farming industry in the Faroe Islands to grow, it has been necessary to move the breeding sites from the more protected fjords to more exposed areas. The more exposed areas place greater demands on the aquaculture installment.

4.2 Environmental approval

Aquaculture production, as well as practically all industry that utilizes resources and/or produces waste, is on the list of particularly polluting activities according to chapter 5 in the environmental protection act (1988), and therefore environmental approvals issued by FEA are required. The approvals impose conditions for operations at each aquaculture site, which are aimed at minimizing the pollution from the fish farms and the impact on the surrounding environment.

There are currently three companies that hold environmental approvals for aquaculture production on the sea in the Faroe Islands. Each environmental approval (fjord) has one or more sites where aquaculture production is allowed. There are 22 environmental approvals for aquaculture production at sea, with a total of 35 aquaculture production sites. There are currently 12 environmental approvals for aquaculture production on land and these are divided among five different companies.

The exact conditions vary a bit between newer and older environmental approvals, but there are general conditions about noise, smell, feed, waste, seabed surveys etc. There are limit values for noise, but there are no quantitative limits on feed, biomass, effluents, medicines etc. This is partly controlled through the approval of production plans for the individual farming cycles.

5 Management framework

5.1 Fish health and welfare

Operations and equipment have to assure good conditions for the fish. Before treatments, that can be rough for fish, for example mechanical and thermal lice treatment, a veterinarian has to sign that the fish is fit for treatment. Farmed fish must be stunned before slaughter.

5.1.1 General biosecurity

The regulations laid down in the departmental order about establishing and biosecurity of aquatic farms (Biosecurity regulation, 2019) are very important for the daily work at the aquaculture sites. The principles have been used since 2003 when the first regulation was put into force. In 2019 the departmental order was revised in order to include biosecurity principles in shellfish and seaweed farming.

The biosecurity regulation lays down minimum distances between aquaculture activities. In one fjord multiple species can be farmed as long as they are at different trophic levels, e.g. one fjord may have one finfish species, one shellfish species and one seaweed farm.

Biosecurity regulations

- The location of a sea farm shall not have a considerable effect on spreading of diseases.
- Distance to other aquaculture activities is emphasized in the approval of locations
- Production type, methods and amounts of production are considered
- The operators at fish farms are responsible for laying out a risk bases for internal control
- The internal control includes identification, description of risks of mortality, introduction and spread of diseases, escapes etc., training of staff and a contingency plan
- Each location has to have a land base where personnel change clothes, equipment is disinfected and dead fish is ensiled
- Equipment has to be disinfected before movement between sites
- The Faroe Islands are divided into management areas, typically on the scale of fjords
- There is only one-year class allowed in each management area, and there is a legislated fallowing period between production cycles
- During well boat transport, valves have to be close
- Dead fish has to be removed, minced and ensiled to PH 3,7 at least five days a week
- Veterinarian control is carried out 6–12 times a year, depending on the size of farm
- ISA surveillance is performed four times a year at each farm.

5.1.2 Sea lice

The purpose of sea lice regulation (2016) is to prevent the spread of salmon lice and development of resistance to pharmacological treatments.

According to the sea lice regulation it is mandatory to report the infestation level of salmon lice at each location at least every 14 days to FFVA. The regulation stipulates how the sea lice counts are to be performed, including that fish from all cages at the location (20 fish from each cage) shall represent the counting and that the sea lice infection at each site is reported as the weighted average with regard to the number of fish in each cage. Furthermore, the regulation stipulates that the counting has to be performed by the independent Aquaculture Research Station of the

Faroe Islands. Lice infestation and use of pharmaceuticals at each locality are published at FFVA´s homepage.

The limit for salmon lice is 1.0 from 1 August to 30 April and 0.5 1 from May to 31 July. If a locality has three consecutive counts exceeding the limit, or four in total, it is required to slaughter all the fish at the site within 11 weeks. Moreover, for each exceedance of the limit, the farm gets one penalty point (e.g. a count of 2.1 adult female with the limit of 1.0 gives two penalty points) and each pharmaceutical treatment gives two penalty points. The number of fish allowed at the farm in the next production cycle is among other things depending on the amount of penalty points:

- < 8 penalty point: increased number of fish
- 8–15 penalty points: same number of fish allowed
- > 15 penalty points: decreased number of fish

Thus, an important factor in the decision for the allowed production at the sites, are the number of lice and pharmaceutical treatments. Production sites with several exceedances of the limits for salmon lice and/or several pharmaceutical treatments have to reduce the number of fish. On the other hand, it is possible to increase the number of smolts if sea lice are well controlled at the farm.

5.1.3 Registration of health and welfare data

All operators are obliged to report data of fish health and welfare to an IT-system named Aliskipan at FFVA, that is designed for aquaculture. Number of fish, weight, mortality, numbered of slaughtered fish, kg feed used, use of pharmaceuticals etc. are reported once a week. Number of salmon lice are reported the day after counting at the latest.

5.2 Environmental monitoring

Environmental monitoring of marine aquaculture is focused on the effects of particulate organic matter and some possibly toxic materials such as copper and zinc. A key requirement is that operators closely monitor levels of pollution at and around production sites. To monitor how aquaculture affects the environment and ecosystems in fjords and straits, operators must carry out tests both inside and outside farming sites (Guidance, 19/2018). The guidance also specifies the international quality standards ISO and NS to be used for sampling and assessments.

Seabed surveys are the basis for environmental monitoring of aquaculture production at the farming sites. Surveys are carried out when fish biomass peak and pollution therefore peaks. According to the environmental licenses, surveys are to be conducted by a laboratory preapproved by the FEA, and thus the surveys are conducted by a third party.

Seabed surveys include two types of tests, i.e. simple assessment and chemical analysis. The simple assessment is an assessment of the seabed condition carried out immediately after sampling. It encompasses four assessment categories:

i. simple fauna assessment: are animals larger than 1 mm present in sample?
ii. pH and redox potential in the top cm of the sample,
iii. sensory assessment: evaluation of bubbles, colour, odour, texture and sludge thickness.
iv. Photos of all samples

The chemical analysis includes testing for copper and zinc contents in sediment, as well as for organic material measured as loss on ignition.

A score system has been devised to assess the condition of the environment based on surveys. Points are allocated to each sample and the level of pollution of the overall farming site is also determined. The level of pollution is grouped into four categories.

- Condition 1 = unpolluted
- Condition 2 = some pollution
- Condition 3 = polluted
- Condition 4 = highly polluted

The result from the simple assessment for each sample is calculated in accordance with annex 2, 3, 4 and 5 in the Guidance, 19/2018, which gives a value that equates to a score for the condition of the environment.

Guideline thresholds have been fixed for copper, zinc, and organic material, as well as for overall level of pollution (Table 5.1).

Table 5.1 Overview of average Faroese background values and guideline warning and limit values for zinc, copper, and loss on ignition

	Average Faroese background values (mg kg^{-1} dw)	Warning values (mg kg^{-1} dw)	Limit values (mg kg^{-1} dw)
Copper	58 ± 14	170	270
Zink	53 ± 11	270	410
Loss-on-ignition	57 ± 20	170	270
Overall assessment of seabed parameters		> condition 2	

The survey frequency is determined by the environmental condition during the previous production cycle. This means that if an impact is detected, more frequent surveys are required. If tests during previous production cycles determined that a site was affected, then testing is also required prior to stocking fish. If the site remains affected when fish is due for stocking, tests are also required halfway through the production cycle (Table 5.2).

Table 5.2 Frequency of seabed surveys

Environmental condition c.f. most recent survey at peak biomass	Next survey is due:
1 – Unpolluted	At peak biomass
2 – Some pollution	Before fish is released at the site and at peak biomass
3 – Polluted	a. Before fish is released and b. If the survey prior to release indicated Condition 1: at peak biomass Condition 2 or 3: when biomass is 50% of peak biomass and at peak biomass Condition 4: FEA will determine sampling requirements
4 – Highly polluted	FEA will determine sampling requirements

After each production cycle the farming operators send in an evaluation of the completed cycle, the results of all seabed surveys and any other relevant information from the completed production cycle and a production plan for the upcoming cycle. Before fish can be released for the upcoming cycle the production plan has to be approved by FEA. In its review of survey results, FEA considers current results for the different parameters, as well as how they compare to previous surveys. If the level of pollution is above the guide warning values and steadily rising, the Environment Agency may order aquaculture practices to be adapted and FEA may order the implementation of necessary measures.

5.3 Marine mammals

Seal predation causes losses in the salmon production. From May 2020 it has been illegal to shoot or by other means to deliberately kill marine mammals at seafarms (Aquaculture act amendment, 2020). Registrations of possible accidental killings due to entanglement are mandatory.

6 Ecosystem/environment interactions

Environmental impacts are one of the limitations for further aquaculture growth. To allow sustainable development and management of the industry there is a need for better understanding of how aquaculture activities interact with the environment. Salmon farming dominates aquaculture in the Faroes ecoregion (Chapter 3). This is also reflected in the monitoring of coastal environments as the only national coastal environmental monitoring is related to salmon farming. In addition, selected water quality parameters are monitored annually in selected fjords. However, various aspects of aquaculture environment interactions are investigated in research projects, although limited in time and space.

6.1 Organic and nutrient effluents from salmon farming

Already in the late 1980s fish farming was the main source of anthropogenic nutrients and organic load to most coastal ecosystems with active fish farming (Mortensen, 1990). Since then, fish farming activity has increased substantially. The total feed use at sea has doubled from 2008 to 2021 (Figure 6.1), and with the development of large smolt at deployment to sea, the on-land feed use has also increased substantially. In 2010, before the trend towards large smolt, the feed use on land was 2% of the total feed. In 2021 the on-land feed use amounted to 7% of the total feed (Figure 6.1).

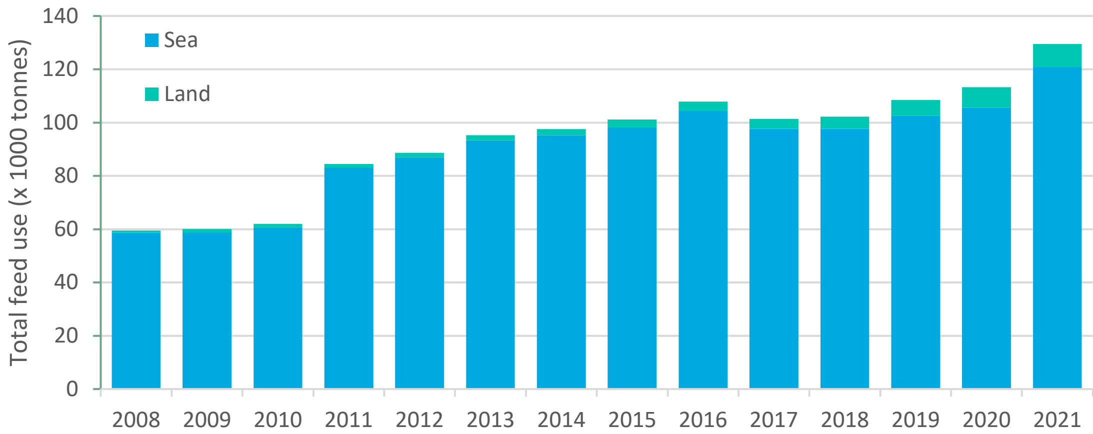

Figure 6.1 Total annual feed uses in the salmon farming industry on land and at sea (Avrik).

The cage systems used in modern marine salmon farms have essentially changed little as the fish are still farmed in net pens with free water exchange ensuring the supply of oxygenated water and waste removal from the pens. However, there has been substantial development in management of feeding strategies and feed composition to reduce the feed convention ratio (Figure 3.3). This also implies that a smaller portion of the waste ends up in the environment. Also, the technological development in farming equipment has allowed fish farming to occur in more exposed areas that can sustain higher biomasses than the sheltered areas.

The local benthic impact of fish farming is investigated thoroughly internationally (Kalantzi and Karakassis, 2006). The environmental monitoring of aquaculture in the Faroes ecoregion also focuses on the local benthic impact (Chapter 5) and has been studied in various projects. At sheltered sites, the local benthic impact can be quite severe, with black sediments and bacterial mats. However, the sites may recover reasonably fast in terms of biogeochemical activity (á Norði *et* *al.*, 2011). In areas exposed to ocean swells, the impact is less severe and recovery may benefit from resuspension of the deposited material caused by the ocean swells (á Norði *et al.*, 2012).

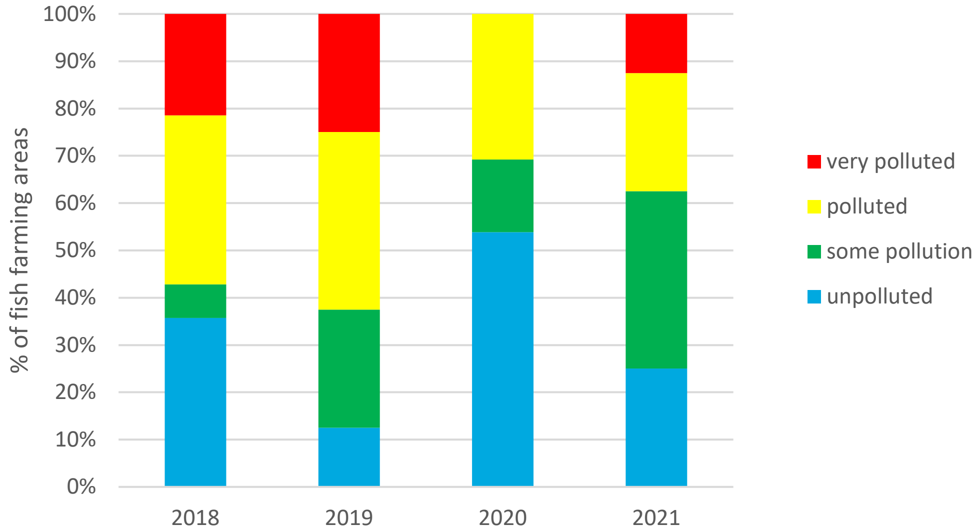

Figure 6.2 Seabed conditions below the net pens at maximum biomass from 2018 to 2021. Classification of conditions are based on redox potential, pH and sensory investigations as well as loss on ignition and the content of copper and zinc in the sediment (The Faroese Environment agency).

Environmental monitoring of the seabed at fish farming areas is a management tool, and if the areas are very polluted actions need to be taken (Chapter 5). Thus, there should be no temporal trends towards more polluted areas (Figure 6.2). Identification and quantification of benthic fauna has also been a part of the environmental monitoring from 1998 to 2014. However, fauna has not been a part of the national evaluation of the environmental status due to lack of consensus on which foreign benthic quality indexes and classification system should be used, given that no national classification system was developed. The fish farming areas that are ASC certified (ASC International) monitor the benthic fauna as a part of the certification.

The data from the national and ASC benthic monitoring is used to develop a benthic macrofauna classification system in accordance with the European Water Framework Directive (WFD). The classification system for benthic macrofauna incorporates depth, sediment Loss On Ignition (LOI) and sediment types as sources of variability in addition to the sediment zinc (Zn) content as a pressure variable. The Norwegian Quality Index (NQI), a multimetric index, having slightly better statistical properties than other tested indexes, was recommended, as long as no Faroese index is specifically developed (Mortensen *et al.*, 2021).

Analysis of temporal trends in benthic fauna indexes at reference sites outside the zone of directly deposition of fish farm waste do not show temporal trends in fauna community in the Faroe Islands (Mortensen *et al.*, 2020).

Dissolved nutrient effluents from fish farming activity may potentially stimulate the primary production (Price *et al.*, 2015). The weak stratification in the fjords with frequent upwelling of nutrients implies that the annual primary production is high and nutrients seldom limit the primary production (Chapter 1). Nutrient limitation and hence potential stimulated primary production based on nutrients from fish farms primarily occur in periods with calm weather.

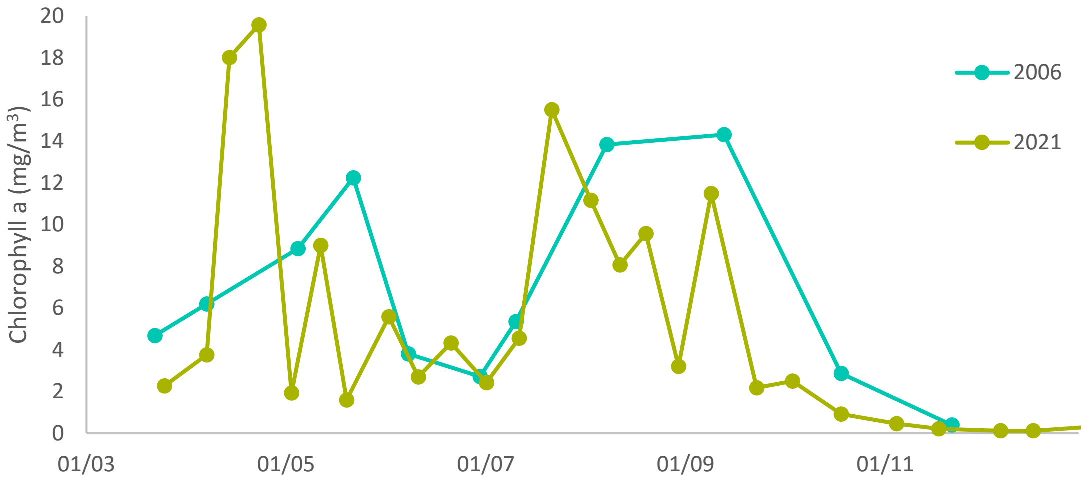

Figure 6.3 Chl *a* measured at 5 m depth centrally in Kaldbaksfjørður. In 2006 there was fish farming activity in the fjord and in 2021 there had been no fish farming for five years (Redrawn from Gaard *et al.*, 2011 and Østerø *et al.*, 2022).

The only area where Chl *a* has been monitored during years with active farming and year without farming is Kaldbaksfjørður (Figure 6.3). Although the time-series are too short to cover the natural interannual variability, they show no clear evidence of changing Chl *a* levels due to fish farming. The fjord is vulnerable towards eutrophication due to a sill at the entrance and periodically stagnant bottom water during summer. However, oxygen measurements do not show obvious changes related to fish farming activity (Figure 6.4).

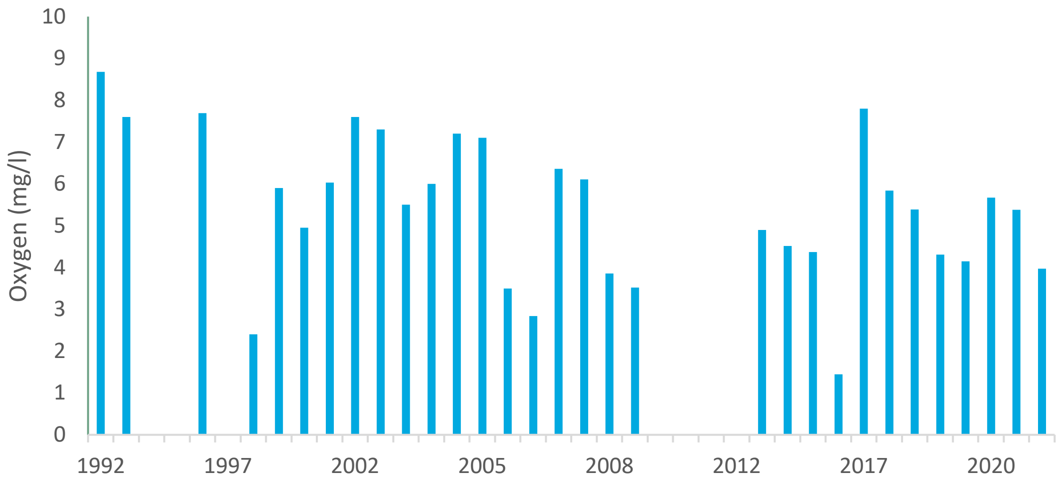

Figure 6.4 Oxygen concentration in the periodically stagnant bottom water (50 to 55 m depth) in Kaldbaksfjørður in late August/early September (Faroe Marine Research Institute).

Altogether, there is little evidence on regional impacts from fish farm derived nutrients and organic material. However, investigations are scarce, and there is an emerging need for national monitoring programmes to produce time-series that would detect such changes. With the development of larger smolt and shorter time at sea, and subsequent higher daily feeding rate per production cycle, the organic load is increasing, making the need for monitoring even more emerging.

6.2 Antibiotics and chemicals

Antibiotics have not been used in the salmon farming industry for decades (Figure 6.5). However, chemicals are widely used for sea lice treatments with declining use at the introduction of mechanical, thermal, and freshwater treatments (Kragesteen *et al.*, 2021).

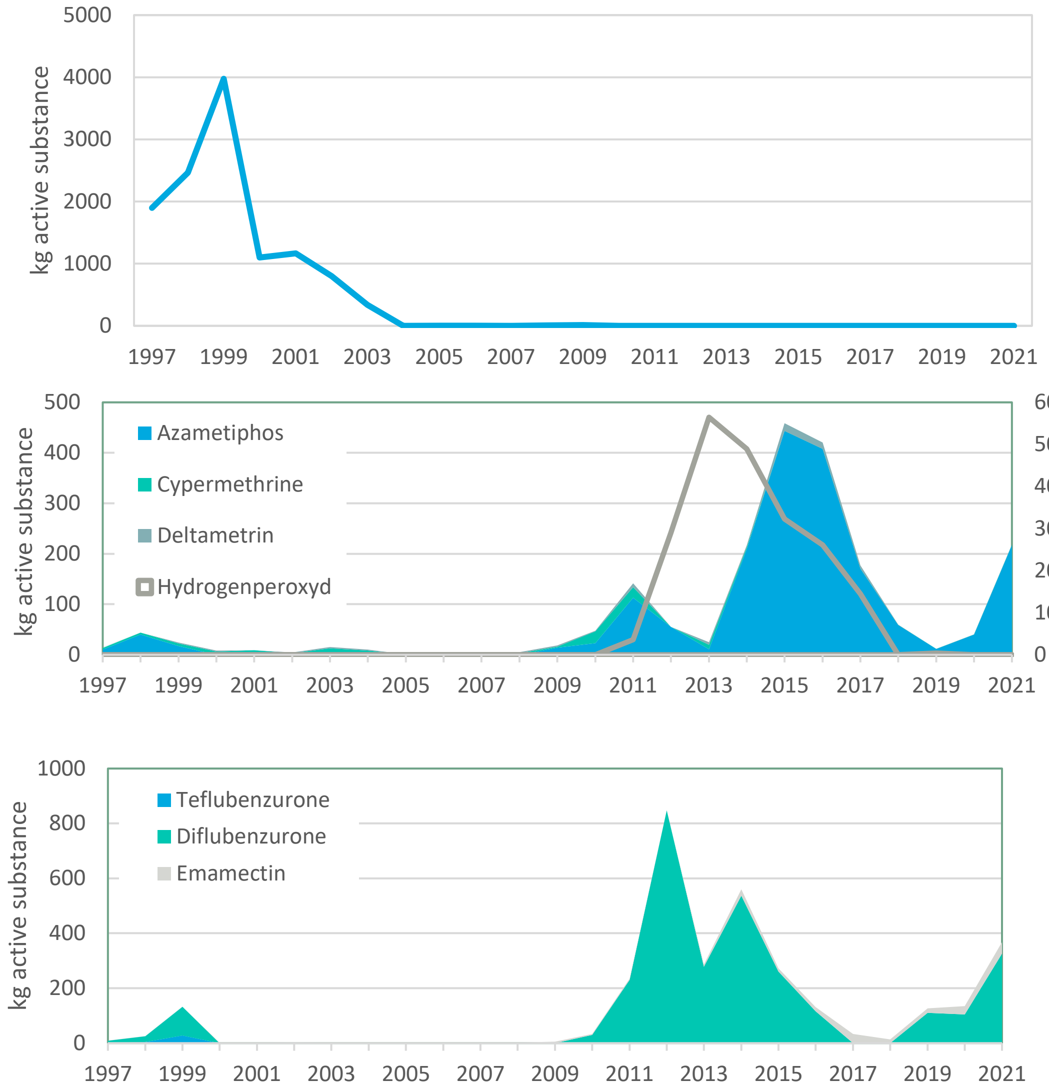

Figure 6.5 Use of antibiotics (upper panel) and chemical use for sea lice bath treatments (middle panel) and oral treatments (lower panel). Bath treatments with hydrogen peroxide are shown on the secondary axis in the middle panel, other therapeutics are shown on a stacked axis (Landsapotekarin).

Between 2011 and 2017 hydrogen peroxide was widely used for chemical treatments, and giving the nature of the treatment agent, it represents the vast majority of chemical use, when reported in weight of active substance. Since 2020, the chemicals used for sea lice treatment are azametiphos, diflubenzurone and emamectin. These have been more or less in use since the beginning of aquaculture in the Faroe Islands (Figure 6.5).

Chemicals have received little attention in environmental monitoring and research projects in the ecoregion. However, one study investigated the occurrence of cypermethrin and diflubenzuron around fish farms where these had been used (Dam and Mortensen, 2013). Cypermethrin was not detected in the environment, but diflubenzuron was detected in all samples in the proximity of the cages when the agent was in use. Compared to the environmental quality standard in Scotland the maximum values were 1/10 of the limit in the Allowable Effects Zone (AZE).

6.3 Sea lice

The two sea lice species that affect farmed salmon in the ecoregion are the salmonid specialist *Lepeoptheirus salmonis* and the generalist *Caligus elongatus*. Salmon lice are present year-round with typically highest abundance on the farmed fish in winter months (Kragesteen *et al.*, 2021). *C. elongatus* shows seasonal abundances as they are present during winter and virtually absent during summer (á Norði *et al.*, 2015). The number of salmon lice on the fish are regulated while the *C. elongatus* are monitored but not regulated.

Salmon lice are managed at production site level and the management of sea lice issues affect the licenced production of farmed salmon at the sites (Chapter 5). There is a substantial effort to diminish the salmon lice issues in the industry and much of the technological development during recent years, such as the production of large smolt to shorten the production cycle at sea, and the gradually movement of farming sites to more exposed areas, is to a large extent motivated by better sea lice control. Recently, a fish farming company has initiated farming in semi-closed units, in order to avoid sea lice infections.

The residual currents flow around the islands and sea lice can be transported to wide distances with these (Kragesteen *et al.*, 2018). Within fjords, it has been shown from empirical data that the level of internal infection is higher, when the distance from the farm to the mouth of the fjord is longer (Patursson *et al.*, 2017). Research has also shown that the management of sea lice in areas where farms are connected by sea lice drifting between farms with the currents, need to be considered at a network level, and that all the connected farms need to keep the sea lice limits and treat for sea lice infections accordingly. If a few farms do not keep the sea lice limit, it will be more expensive for the other farms in the network, and the profitability for the aquaculture industry as a whole will decrease (Kragesteen *et al.*, 2019).

6.4 Cleaner fish

Lumpfish health and cleaning efficiency have been extensively studied in lumpfish at commercial farms. All the fish farming companies use lumpfish as cleaner fish to some degree, and the welfare is regularly monitored, resulting among others in the development of a liver colour scoring index as a measure of health and welfare condition (Eliasen *et al.,* 2020). It is against the legislation to transfer lumpfish between sites and production cycles. After each completed production cycle, the lumpfish thus are removed and destroyed to prevent disease transfer. The cleaning efficiency of lumpfish show clear seasonal variations as they rather prey on zooplankton than salmon lice when available. On the other hand, biofouling and the availability of associated prey organisms surprisingly seemed to have a positive effect on the cleaning efficiency (Eliasen *et al.*, 2018).

6.5 Fish welfare

With the establishment of salmon farms in more exposed areas, knowledge of the welfare and behaviour of salmon in such surroundings is needed, and the fish farming equipment needs to be designed accordingly. At a commercial farm exposed to significant wave heights up to 3 m and current velocities up to 50 cm/s, the salmon choose to occupy the area in the cage exposed to the strongest currents and avoided the surface in high waves (Johannesen *et al.,* 2022). The cages deformed in rough seas reducing the vertical space availability. Nevertheless, the welfare score was still high as few injuries were observed.

When farming in areas exposed to ocean swells where the waves have longer periods and thus reach deeper it thus should be considered to make the cages more resistant to deformation and deep enough for the fish to escape the effect of the waves (Johannesen *et al.*, 2022).

The introduction of mechanical, thermal, and freshwater treatments also implies more handling of the farmed fish, and this is one of the reasons for increased mortalities during the recent years (Figure 3.4). It is especially the mortality on large fish that has increased due to handling connected to delousing activity (Figure 6.6). To limit the mortality, a fish health check and approvement for treatment performed by a veterinarian is mandatory.

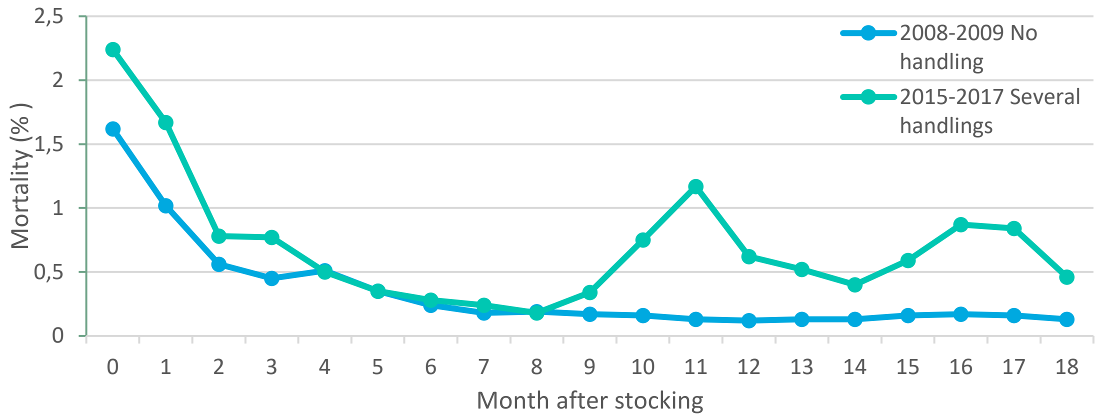

Figure 6.6 Mortality at sea per month from stocking the smolts (% of stocked fish count) in years with limited handling of the fish (2008–2009) and in years with severe handling, just after the introduction of thermal and mechanical delousing in the ecoregion (2015–2017) (Avrik).

6.6 Wild fish interactions

There is no historical record of a natural wild salmon population in Faroese rivers or fjords, and Atlantic salmon are considered non-native (Seafood watch, 2018). Accordingly, there is little focus on genetic interference due to escapes, however, escapes might interfere with the salmon stocking program of the interest group, Føroya Sílaveiðifelag.

Sea trout are naturally occurring in the islands and have been monitored since 2019. The main emphasis has been on establishing the seaward migration period and the abundance of salmon lice on the trout. During the three investigated years, the seaward migration period has been concurrent with periods of high precipitation and has varied from mid to late May to mid to late June (Eliasen *et al.*, 2022). Abundance of sea lice on trout is based on reporting from anglers and trials with gillnets. Most trout are caught from May to August and during this period, the prevalence of sea lice regularly is above 50% with an average abundance between 5 to 10 lice per fish (Eliasen *et al.*, 2022).

6.7 Marine mammals and seabirds

Grey seals frequently interact with salmon farms as they feed near the farms and in some cases even enter the cages. In 2020 it was banned to kill seals as a protective act, when interacting with fish farms (NAMMCO 2016) and prior to the ban there was a declining trend in seal shootings (Figure 6.7). Although there is a ban on lethal control, accidental mortalities such as entanglement may still occur, and such incidents must be registered. According to Havbúnaðarfelagið, no marine mammal mortalities have occurred since January 2021 (Seafood-watch, 2022).

In 2016 the Scientific Committee working Group on Coastal Seals (NAMMCO, 2016) concluded, that grey seal shooting at salmon farms could have a negative impact on the grey seal stock. The conclusion was based on lack of knowledge of the grey seal stock and stock assessments were recommended. In 2018 counting of seals was initiated but the data are still too scarce for stock assessments (NAMMCO, 2021).

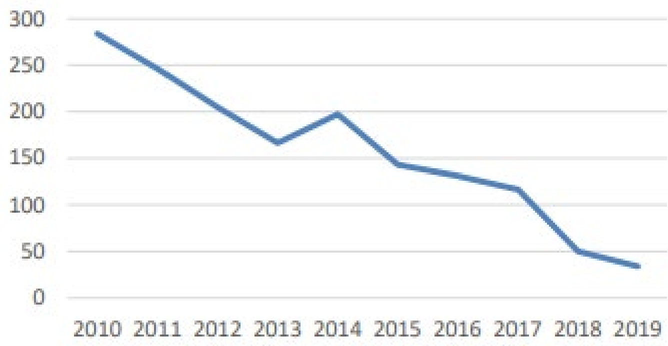

Figure 6.7 Number of seals shot at salmon farms in the Faroe Islands from 2010 to 2019. Killing of seals was banned in 2020 (NAMMCO, 2021).

Due to improvements of the nets, seabird mortality as a result of entanglement in fish farm bird nets, has steadily declined and in 2017 the estimated total bird mortality was ~100 birds (Seafood watch, 2018). In 2021 an average of 2.1 bird mortalities were recorded per site (Seafood watch, 2021), adding to 53 bird mortalities in total assuming that the number of active sites was 25.

European storm-petrel, of which Faroe Islands holds the largest breeding colony in Europe (Bird-Life International, 2022) is known to aggregate around fish farms (Aguado-Giménez *et al.*, 2016). In a preliminary study, the species has also been observed at fish farms in the Faroe Islands (Porter, 2021).

6.8 Seaweed farming

Seaweed farming started on trial basis in 2010 in the ecoregion and has steadily increased since then. In the onset of seaweed farming, the farms were located at sites dedicated to salmon farms thus relying on goodwill from the fish farming companies. In 2020 first site licences dedicated to seaweed farming were distributed. Today it is mostly *Saccharina latissima* and *Alaria esculenta* are farmed, but other local species are also tested. The nutrient rich environment in the Faroese fjord make good growth conditions for seaweed (Mols-Mortensen *et al.*, 2017, Bak *et al.*, 2018). However, biofouling and grazing towards the end of the growth season may diminish the output and quality of the product (Koester, 2022).

Since seaweed extract nutrients and carbon from their surroundings, the environmental interactions of seaweed farming are generally mostly discussed in a positive and restorative manner, e.g. as integrated multitrophic aquaculture (Troell *et al.*, 2009). Farmed seaweed may also act as habitat and shelter for various species including commercial fish stocks. However, as they may be heavily grazed, especially by the snail *Lacuna vincta* (Schlund, 2022), unwanted alterations of the ecosystem may occur.

6.9 Shellfish farming

Currently there is no commercial scale shellfish farming in the ecoregion. Trials with blue mussel farming have however shown potential for farming with wild spat collection (Danielsen and á Norði, 2021). Like seaweed farming, no feed is added to the environment and on the contrary, the species extract organic particles from their surroundings. Thus, blue mussel farms are considered in integrated multi-trophic aquaculture (Chopin *et al.*, 2012) and in an ecosystem restoration manner (Small *et al.*, 2019). However, there are also negative impacts from suspended shellfish farming, such as deterioration of the seabed below the farm due to increased deposition of organic matter (McKindsey *et al.*, 2011).

7 Social and economic context

This chapter focuses on some of the economic and social aspects of the Faroese aquaculture industry. In order to encompass most of the effects, the analysis is conducted on three levels. At the industry level, the economic profitability of the industry is described, at regional level the effects of the industry on the regional labour markets and the age and gender distribution of the labour force in aquaculture is presented and at the national level the contribution of the industry to the national economy is described.

7.1 The profitability of the aquaculture industry

For being economically sustainable, the industry needs to generate profits. The profitability of salmon production has varied substantially over time, mainly as a result of biological factors (e.g. disease outbreaks). For the same reason, concerns for diseases have historically been the limiting factor for production

The period from 2000 to 2010 was heavily influenced by first the ISA disease outbreak (Chapter 3) and later the financial crisis. Since 2005 there have been no major outbreaks of diseases, which has led to a more stable production environment and higher profits. Since 2012 the industry has entered a new normal, without any significant disease outbreaks, high sales prices, and large profits (Figure 7.1).

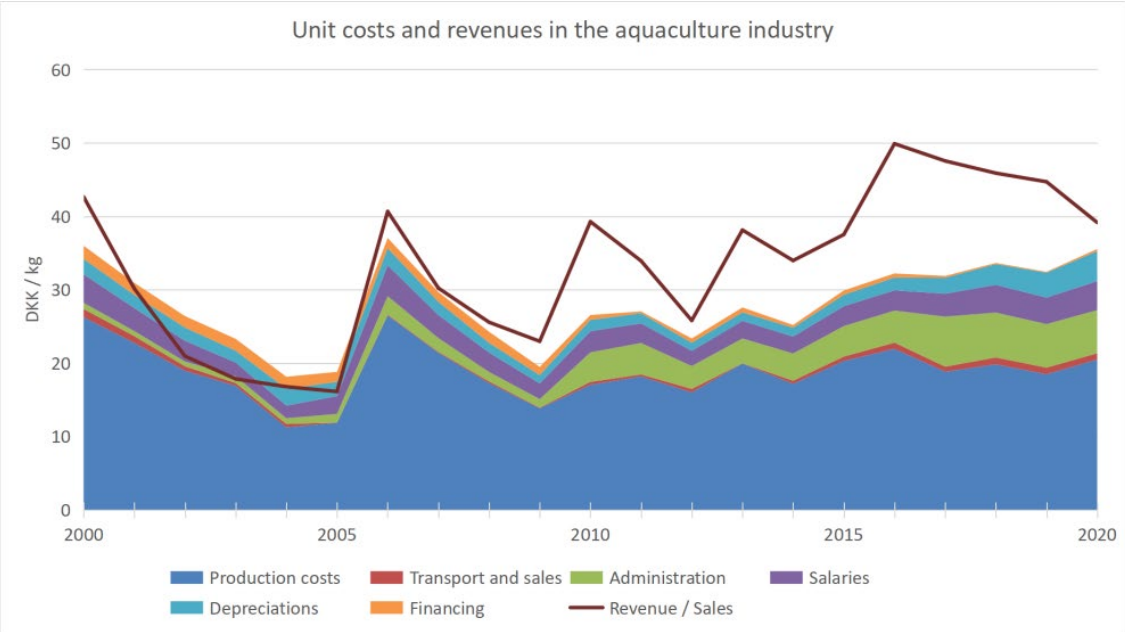

Figure 7.1 Unit costs and revenues in the aquaculture industry. Unit costs are calculated as costs divided by the slaughtered weight. The line depicts the revenue per produced kilo of salmon while the area chart depicts the cost structure of the industry. The space between the revenue line and the cost area represents the profits or deficits of the industry (Statistics Faroe Islands, Statbank, Business statistics).

The higher profits in recent years have largely been driven by the increasing price of salmon (Figure 7.2), which has increased from 16 DKK kg^{-1} in 2003 to over 50 DKK kg^{-1} in recent years. Although production cost also has risen in the same period, the price has increased substantially more, causing the profits to surge. One reason for the price increase are the management restrictions many countries have imposed on the production of salmon, mainly to combat diseases and salmon lice. This has made the supply lacking behind the demand.

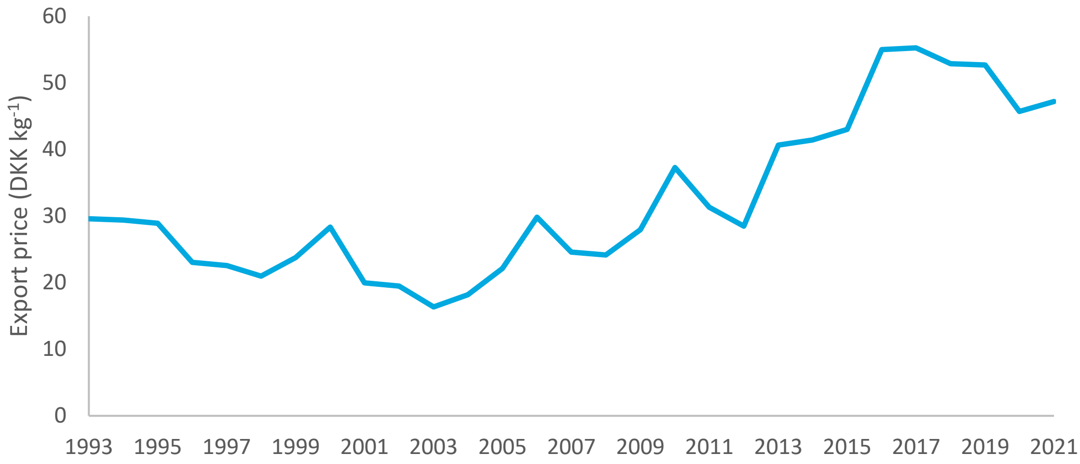

Figure 7.2 Annually averaged export prices of whole chilled salmon from 1993 to 2021, which constitutes ~70% of the total salmon export in the ecoregion (Statistics Faroe Islands, Statbank, export statistics).

In addition, Faroese salmon receives a price premium, i.e. a higher price compared to the benchmark price, on the market (Figure 7.3). At times, the price premium has been as high as 7 DKK kg-1 salmon, which is a substantial premium. In 2021, the price premium declined to around 4.50 DKK kg-1, which still is quite significant.

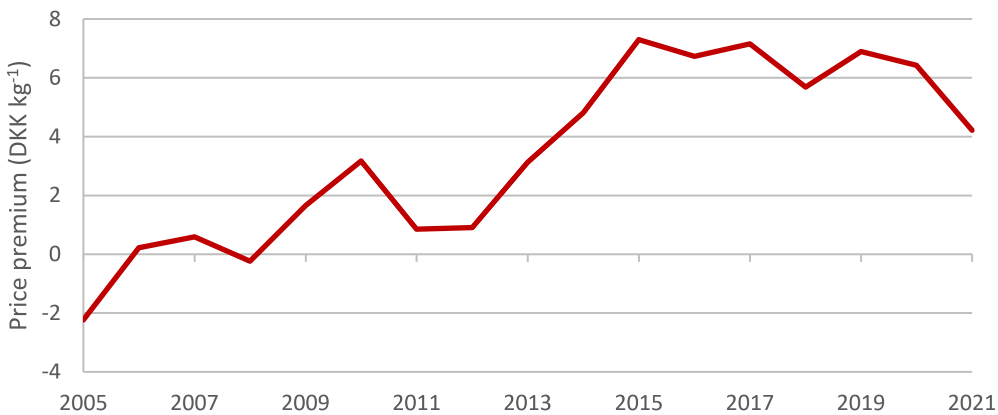

Figure 7.3 The price premium in DKK of Faroese salmon compared to Norwegian salmon (Garshol (2020) and Nystøyl, 2022).

One of the explanations for the high price premium on Faroese salmon compared to Norwegian salmon is the size of the harvested salmon (Figure 7.4). In the Faroe Islands the weight at harvest is substantially higher than in Norway, which is the world's largest salmon-producing country. In addition, the weight at harvest has been increasing over time (Figure 7.4). Other potential influencing factors are the exclusivity associated with the Faroe Islands and superior quality.

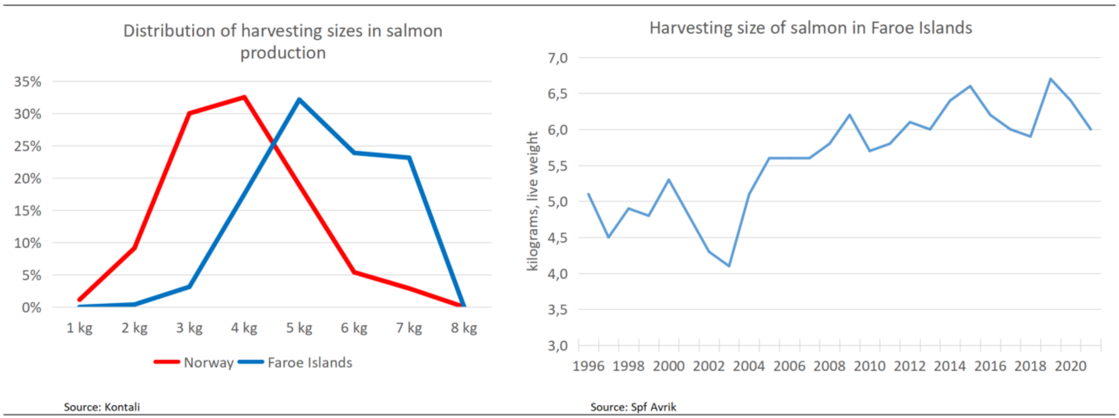

Figure 7.4 The weight of salmon harvested in Faroe Islands and Norway (left panel) and the average size of salmon harvested in the Faroe Islands from 1996 to 2021 (right panel) (Garshol, 2020; Dam, 2022).

During the period 2001 to 2005 the aquaculture industry experienced large deficits due to the ISA disease. Since 2006 the profits have steadily grown and the operating margin has been high. This high profitability can be linked to the absence of major diseases and growing international market demand.

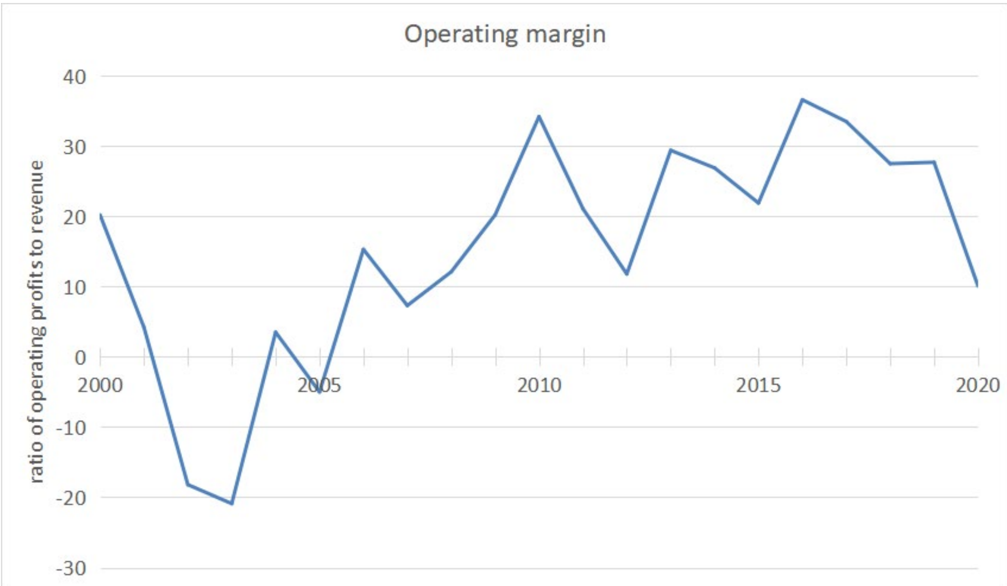

Figure 7.5 Profitability measured by the net profit ratio (Statistics Faroe Islands, Statbank, Business statistics).

In recent years, salmon lice have been one of the major challenges for the industry. Therefore, large investments have been made to combat salmon lice. The investments have mainly been made in on land facilities, extending the production time on land to reduce the production time in the fjords and hence the exposure to salmon lice. Though the main driver behind the investments has been the salmon lice, the change in the production pattern is also expected to have an effect in reducing other diseases, and better exploitation of the available sites.

Investments in the aquaculture industry have increased from around 100 million to around 500 million DKK annually (Figure 7.6). As a result, the total value of the tangible assets in the aquaculture industry have increased from around 500 million DKK to around 3500 million DKK.

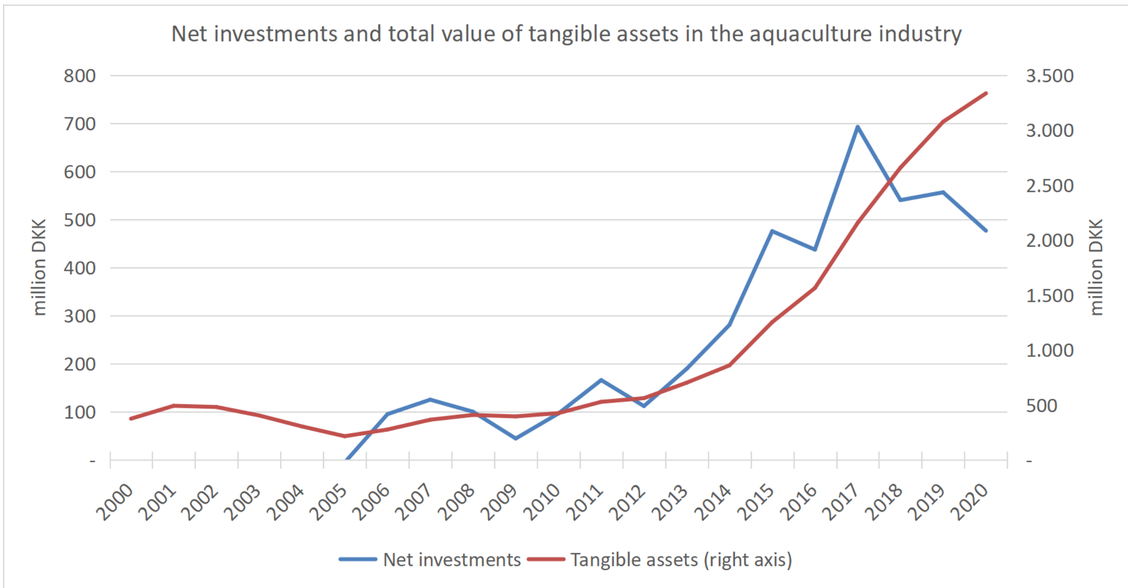

Figure 7.6 Net annual investments (left axis) and total value of tangible assets (right axis) in the aquaculture industry (Statistics Faroe Islands, Statbank, Business statistics).

The success by investments in reducing the production cycle at sea are visible in the production data (Figure 7.7). As an example, the production cycle at sea at a specific aquaculture site has reduced by more than eight months and thus the fish was harvested before the internal infection pressure of salmon lice had escalated, reducing the need for delousing operations (Figure 7.7).

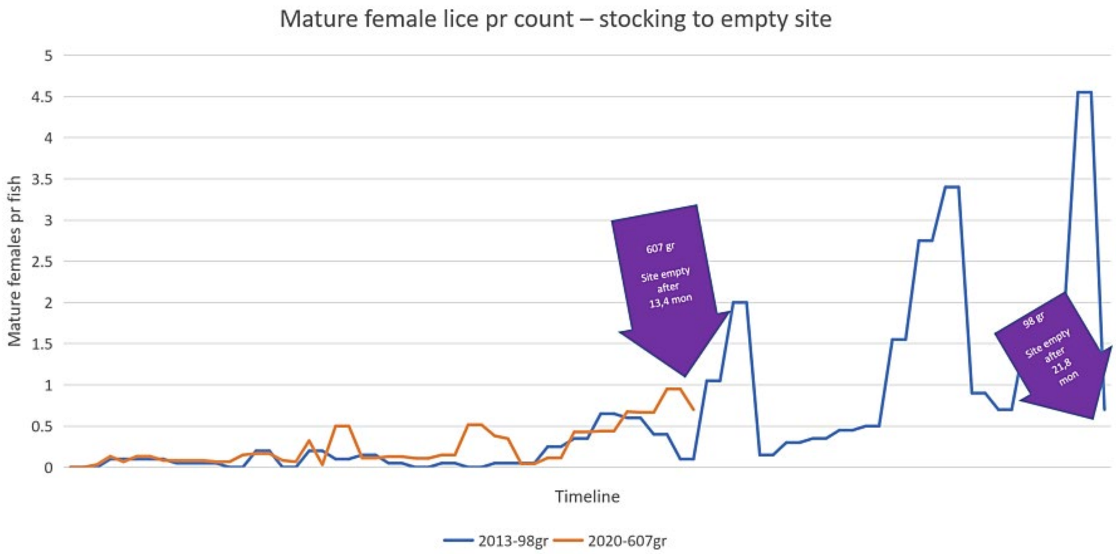

Figure 7.7 Abundance dynamics of adult female salmon lice on farmed salmon during two production cycles at a specific aquaculture site. The timeline represents time since the smolt were transferred to see. The average weight of smolts stocked in 2013 was 98 g, while the smolt stocked in 2020 were 607 g. In 2013 the production cycle at sea was 21.8 months while it was 13.4 months in 2020 (Dam, 2021).

The combination of large profits and investments has changed the cost structure of the industry (Figure 7.8). Production costs, which mostly are related to smolt and feed, have increased relatively less compared to other cost groups. Depreciations have increased the most, which is a result of the large investments in recent years. These investments have mostly been self-financed and thus the financial costs have decreased. The other cost groups, administration, salaries and transport and sales, have increased at a relatively steady pace.

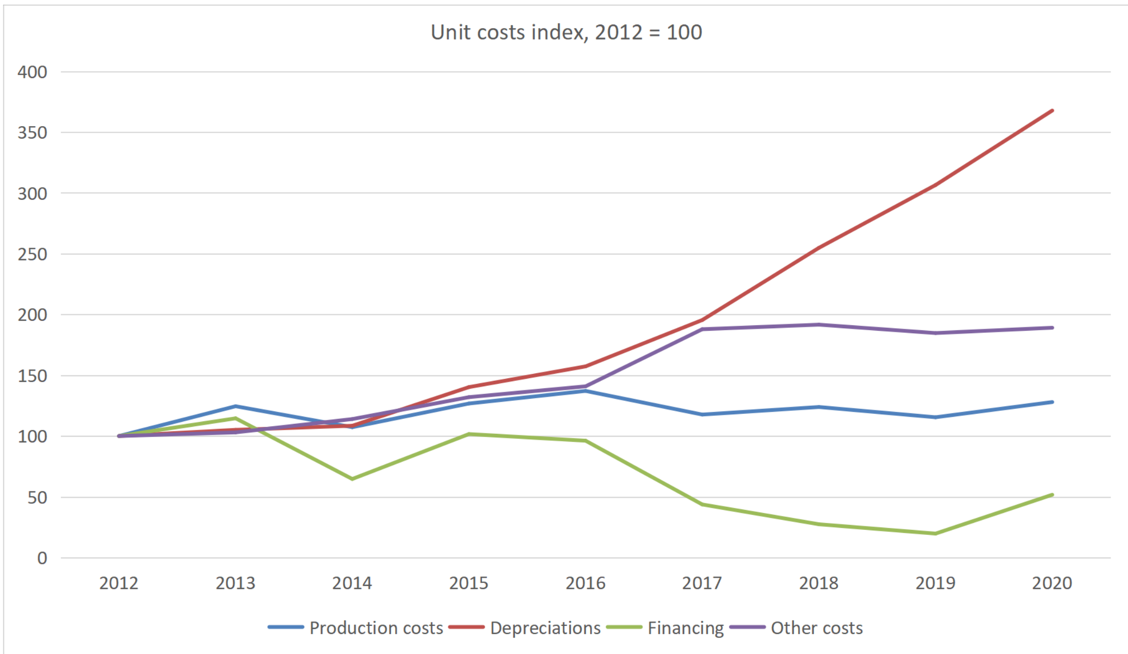

Figure 7.8 Temporal trend in unit cost indexes normalized to 2012 (Statistics Faroe Islands, Statbank and Sjókovin).

7.2 Regional impacts of the aquaculture industry

The effects of the aquaculture industry on society are visible through the labour market since an important social impact of industries is the jobs and employment opportunities they provide, creating a foundation for settlement and population.

The employment in aquaculture has increased over time, concurrent with the increase in production (Figure 7.9). At the same time, the employment in fisheries and processing of wild catches has decreased, making aquaculture an increasingly more important industry in Faroe Islands in terms of job creation.

In 2021, the aquaculture value chain including farming (breeding, juvenile production, and grow-out), slaughter and processing, employed about 1350 people which was around 5% of the total active labour force. In addition to the direct employment in the industry, there was a substantial employment at suppliers delivering services, goods, and equipment to the aquaculture value chain.

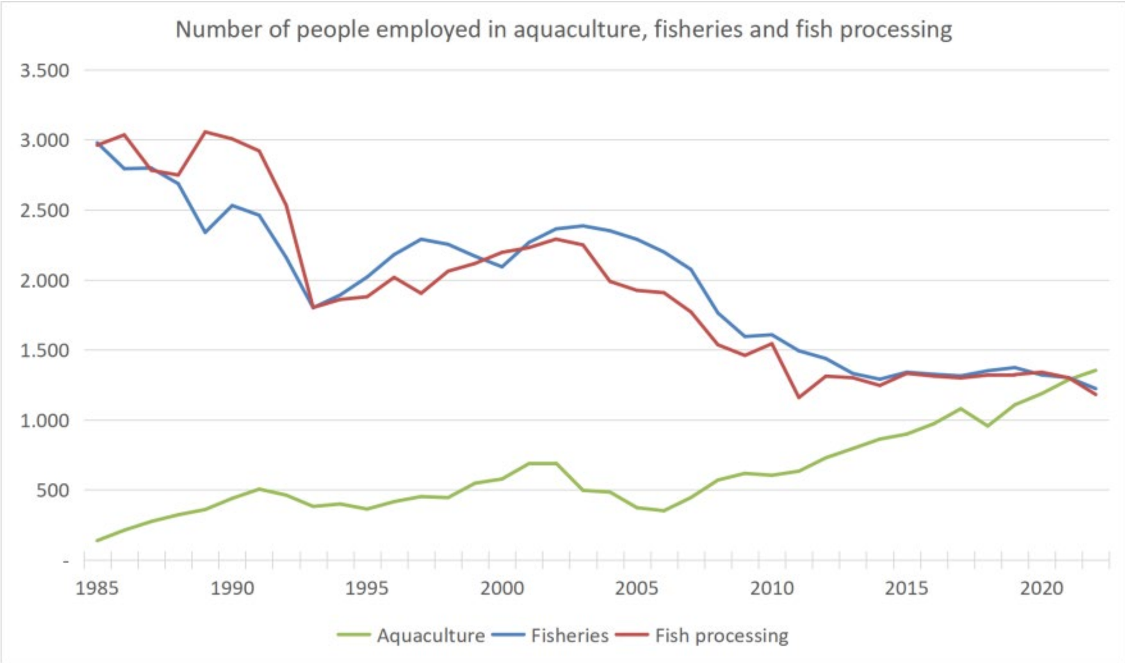

Figure 7.9 The employment in aquaculture production and processing of salmon, and in fisheries and processing of wild catches. Source: Statistics Faroe Islands, Statbank.

The people working in aquaculture are relatively young (Figure 7.10). Around 8% of the labour force in aquaculture are in the age group 20–24 years. In general, there are more men working in the industry compared to women. As of 2021 6% of the men worked in aquaculture compared to 4% of the women.

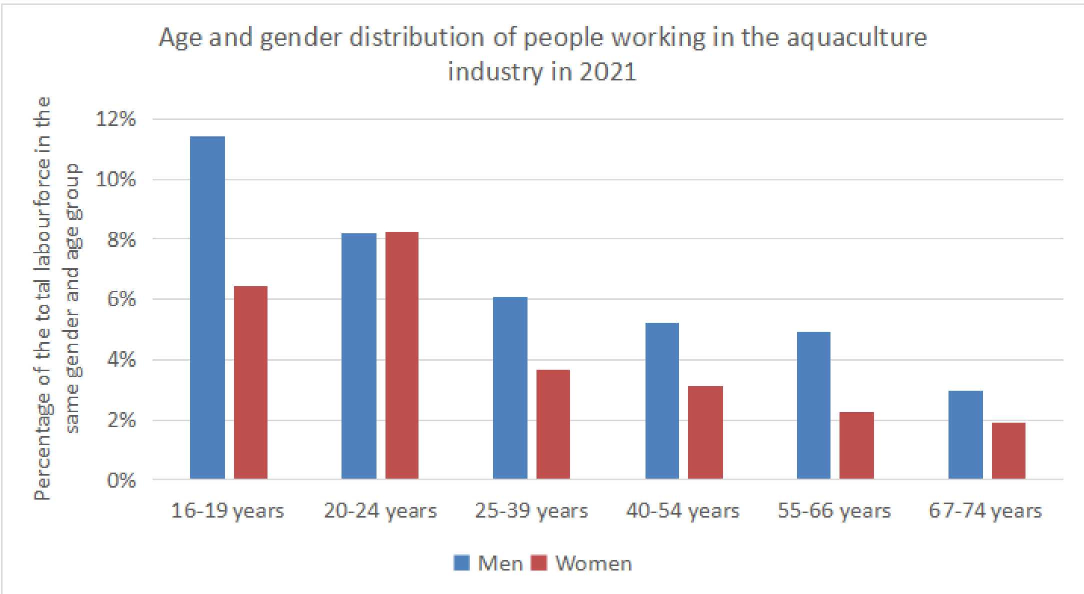

Figure 7.10 Age and gender distribution of people working in the aquaculture industry (Statistics Faroe Islands, Statbank).

Many women born outside the Faroe Islands work in aquaculture and fish processing compared to other industries (Figure 7.11). More than one third of the female workforce in the aquaculture industry and 40% of the female workforce in fish processing are born outside the Faroe Islands. This is substantially higher than that in industry other than fisheries and aquaculture where the corresponding figure is about 13 %. This indicates that the aquaculture and fish processing industries are successful at integrating non-Faroese women in the workforce.

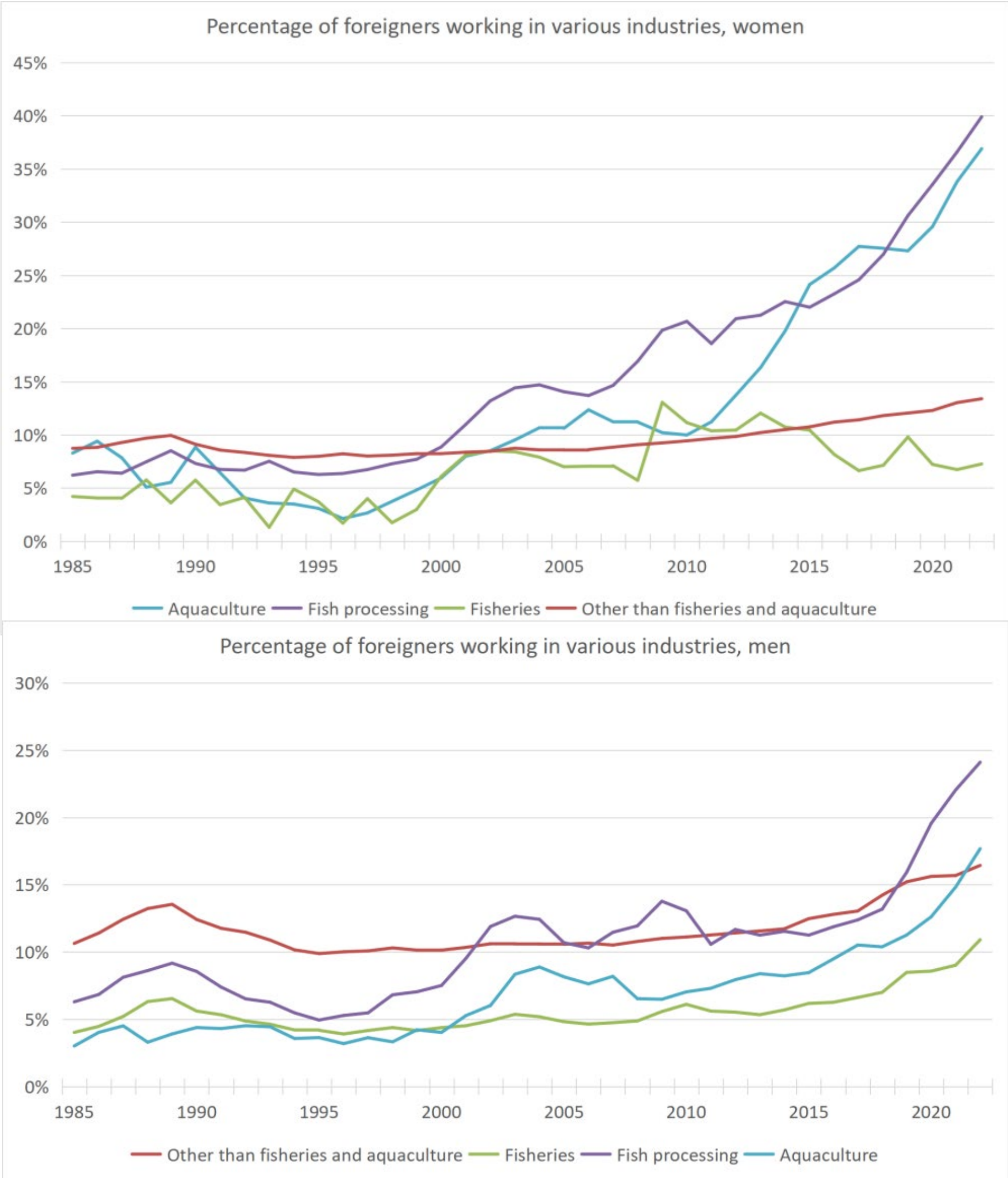

Figure 7.11 The percentage of women (upper panel) and men (lower panel) born outside the Faroe Islands working in various Faroese industries (Statistics Faroe Islands, Statbank).

The number of men born outside the Faroe Islands working in the aquaculture industry has also been growing in recent years, but to a lesser degree than in the case of women (Figure 7.11). As of 2022 around 18% of the male workforce in aquaculture were born outside the Faroe Islands, compares to 37% of the female workforce. In the fish processing industry around 24% of the male workforce were born outside the Faroe Islands. Overall, about 80% of non-faroese workers within aquaculture come from countries outside Europe (Statistics Faroe Islands).

The infrastructure on the Faroe Islands is well developed and the northern islands Vágar, Streymoy, Eysturoy and Norðoyggjar are connected by subsea tunnels and bridges and can to a large degree be seen as one connected labour market. In 2023, Sandoy will be connected via a subsea tunnel, whereby around 90%of the labour market can be seen as one integrated labour market, leaving only Suðuroy as a separate labour market. Since the Faroe Islands are a geographically small area and connected, the regional distribution of jobs is less important than in other countries.

Prior to the ISA-disease in the earlies 2000s, aquaculture activities and employment were mainly in the four regions Norðstreym, Suðuroy, Norðoyggjar and Vágar (Figure 7.12). The ISA-disease led to a lot of bankruptcies and a consolidation of the industry into two regions, Eysturoy and Vágar. There can be seen a clear effect on the labour market, where people in Eysturoy and Vágar are increasingly working in the aquaculture industry, while other regions show stagnating tendency. In 2018, a special regulation on the region of Suðuroy was activated (Regulation on aquaculture processing in Suðuroy, 2018). It stated that the fish produced in Suðuroy must be processed locally. This has led to an increase in the employment in aquaculture in Suðuroy (Figure 7.12).

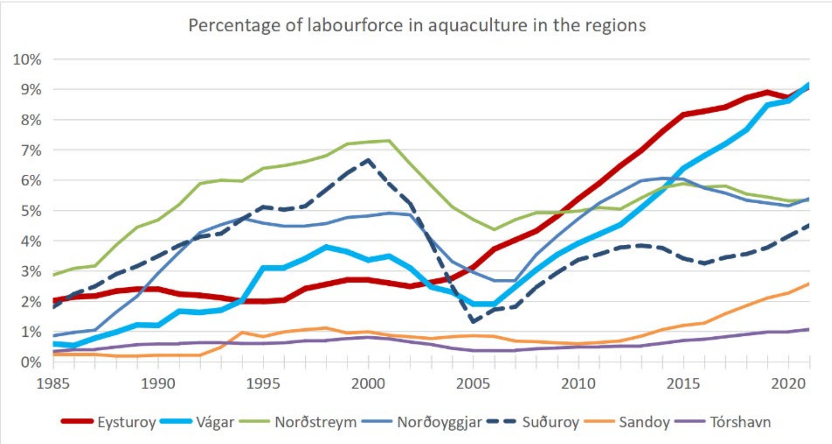

Figure 7.12 Geographical distribution of the labour force working in the aquaculture industry shown as the percentage of the total active labour force. The location of the regions is shown in the right figure (Statistics Faroe Islands, Statbank).

7.3 National importance of the aquaculture industry

One way to view the importance of the aquaculture industry is to look at the sector's direct contribution to the economy. The Gross Domestic Product (GDP) is the total revenue of a production minus the costs of the physical inputs.

The aquaculture industry is a major contributor to the GDP (Figure 7.13). Prior to the ISA disease the industry's share of GDP was around 4%. In recent years this has increased to around 8% of the total GDP in factor prices, though somewhat lower in 2020 due to the COVID-19 crisis. There is also a lot of demand effects on other sectors from both the aquaculture industry itself and also from all the employees in the industry. Thus, through the multiplier effect the industry's contribution to GDP is much larger than the stated 8%.

There are no recent surveys of the multiplier effects, but a survey from 2015 indicates a direct multiplier of around two in aquaculture, indicating that around 16% of the total GDP originates directly and indirectly from aquaculture. Two thirds of this effect stem from purchases of goods and services within the industry, whilst the remaining third originate from the ripple effects from the employees' consumption. In addition to this, the survey showed that there are additional effects from the fact that the aquaculture industry is financing a part of the public sector, and historically, a growth in public revenues from the aquaculture sector has always led to increased public spending. The increased public spending then brings the total multiplier up to around three, indicating that the aquaculture sector is the source of around 24% or a quarter of the total economy (Laksáfoss, 2015).

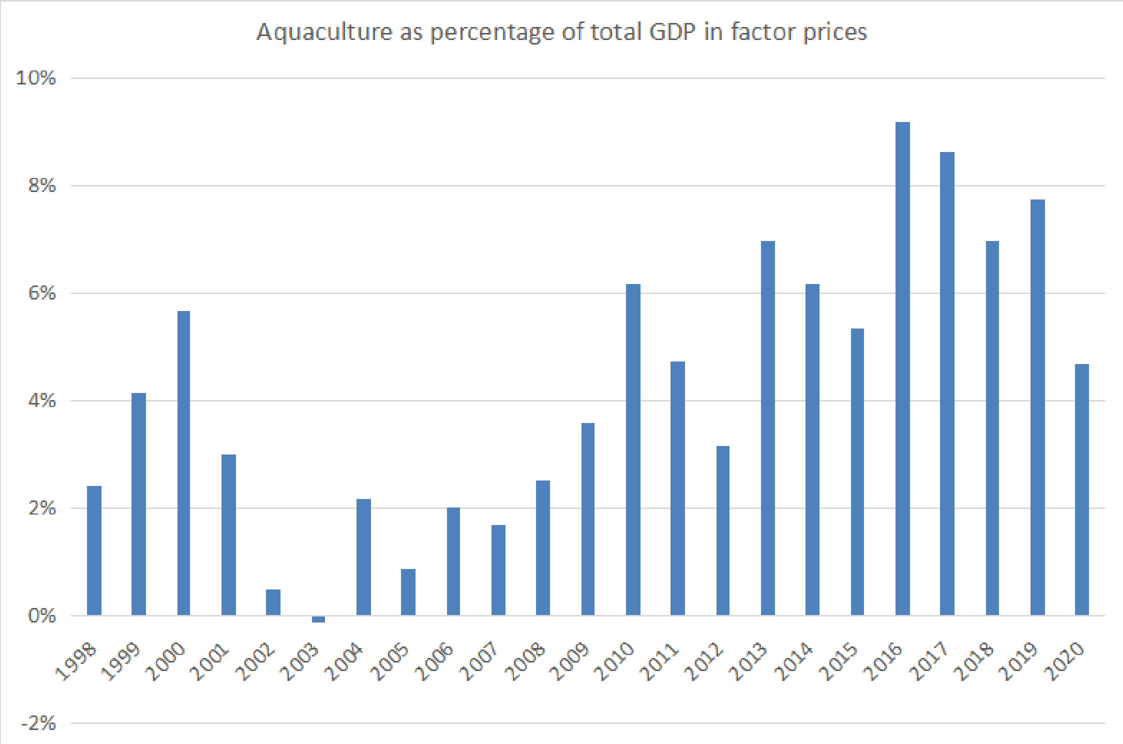

Figure 7.13 Share of the aquaculture industry relative to the total GDP in factor prices (Statistics Faroe Islands, Statbank).

In recent years, the exports from the aquaculture industry have been around 40–45% of the total exports of goods, and around 27% of the total income on the balance of payments (Figure 7.14). This clearly indicates the aquaculture industry's importance to the society as a whole. Faroe Islands is strongly dependant on imports, which makes the exporting sector a crucial component of the economy, since it is the source of finances for the whole economy. Thus, aquaculture has grown to be one of the most important sectors in the Faroese economy.

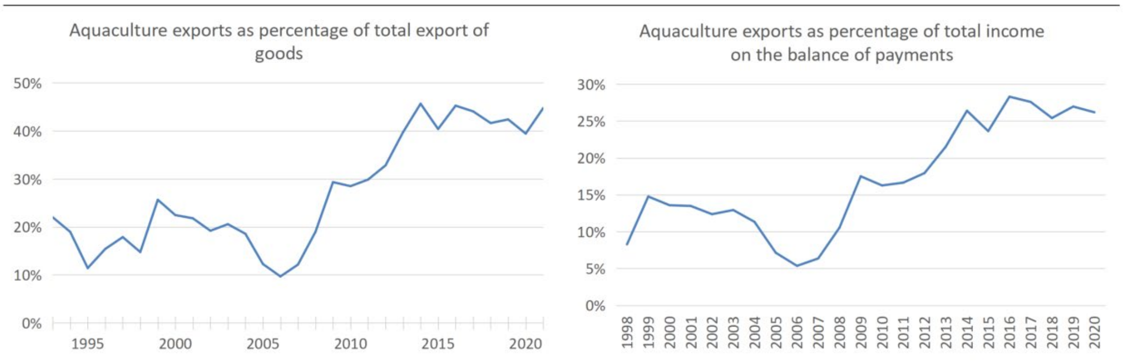

Figure 7.14 The exports from the aquaculture industry in percent of total exports of goods (left panel) and as percentage of the total income on the balance payments (right panel) in Faroe Islands (Statistics Faroe Islands, Statbank).

Three types of taxes are paid by the industry, namely corporation taxes, capital gain taxes and production taxes (Table 7.1). The production tax is a tax on slaughtered salmon which was introduced in 2014. The total taxes have been around 500 million DKK annually. In addition, income taxes from the employees in the aquaculture industry and derived industries can be added. Thus, it can be concluded that the aquaculture industry is a major contributor to the total public income.

Table 7.1 The aquaculture industry's direct contribution to the public revenue, through taxes. Source: Umhvørvis og vinnumálaáðið, 2020.

Income from aquaculture industry (mio. DKK)	2015	2016	2017	2018	2019	2020
Corporation taxes	154	210	246	177	211	
Capital gains taxes	76	108	110	141	113	
Production taxes	12	161	158	136	140	82
In total	241	478	515	455	465	

7.4 Public Acceptance of Aquaculture

The public commonly associates aquaculture with both positive and negative effects for the public which vary greatly depending on the specific contexts (Alexander *et al.*, 2016; Hynes *et al.*, 2018; Cantillo *et al.*, 2023). It is seen as an economic benefit and a critical source of employment in coastal regions and important for food security. Some of the negative aspects relates to harmful environmental impacts.

There is no published literature in the Faroe Islands focusing on the public's acceptance of aquaculture. There are, however, no indications that suggest any general public resistance to aquaculture operations. There are no environmental NGOs present in the Faroe Islands which oppose aquaculture development. However, a survey sponsored by Føroya Nátturu og Umhvørvisfelag (FNU 2022), with 500 respondents from the general public, showed that 67% of respondents 'agreed' that the aquaculture industry should be subject to stricter environmental regulations. This indicates that there might be some 'silent' environmental concern regarding the activity. The lack of research concerning the public perceptions towards aquaculture is a major knowledge gap, and presents a critical data gap with respect to the ability to assess the social sustainability of the sector.

8 Interaction of environmental, economic and social drivers

There have been many drivers for the development of aquaculture on the Faroe Islands, and these have involved many sectors. The pioneering attempts of the development involved the government, authorities as well as individuals who saw the potential of a new industry (Jacobsen, 2011).

The ISA crises in the early 2000s is an example where environmental, economic and social drivers simultaneously caused an extreme decline in the otherwise expanding production (Figure 3.1). The major reform in the aquaculture in 2003 was a collaboration between the industry, financial institutions and the authorities, which laid the ground for today's aquaculture (Jacobsen, 2011).

The aquaculture industry has continuously grown. A development that has involved the aquaculture industry itself, the government and authorities, researchers, technological developers and cooperation abroad. As mentioned in section 7, there are large ripple effects, such as development and production of farming equipment, feed and logistics. Thus, the aquaculture industry, together with various suppliers has huge social and economic effects on the Faroese society.

The legislation for marine aquaculture, is grounded in sustainable aquaculture as the allowed production at the various sites directly depends on fish welfare, sea lice management and environmental impact (Chapter 5). Thus, the legislation directly motivates the aquaculture to farm in a sustainable manner, but it is also highly important that the knowledge of possible environmental impacts and tools for proper management are available.

The coastal area is a zone of multiple stressors as human use of ocean area is greatest in coastal areas (Halpern *et al.*, 2015). There are multiple stakeholders in the coastal areas of the Faroe Islands, these are coastal fishers, landowners, environmental NGOs, local communities and citizen groups.

Currently there is no overall spatial planning for use of the coastal area. However, activities in the coastal area require licences. For aquaculture, the coastal area is divided into management areas, on the scale of fjords. Only one fish farmer is allowed in each management area. Farming licences for low trophic species may also be issued in the management areas, provided, that these are of no risk to the fish farming activity in the area (Aquaculture act, 2009).

In addition to the division into management areas, a site licence is required for the aquaculture operations (Chapter 4). When site licences are issued or changed, this is often upon the request of the fish farmers who apply to the Food and Veterinary Authority. If they approve the site with regards to distance requirements to other activities, e.g. food safety (Chapter 4) the matter is sent to relevant stakeholders for hearing. The stakeholders are typically the local districts, and other stakeholders such as lobster fishers. The Food and Veterinary Authority holds the final decision on site licences. In case of spatial conflicts between fish farms and other aquaculture activity the fish farming activity holds privilege (Aquaculture act, 2009).

Regarding competition for space, there is traditional lobster fishery in some fjords and sounds and these largely operate in the same areas as the aquaculture industry, and cases have occurred where these two sectors have competed for the same areas (Bogadóttir, 2020). Furthermore, the gradual expansion of salmon farms to exposed areas may also lead to competition for space with the traditional coastal fishery in near future. Traditionally, a large number of fishing boats, using jigs, longlines and small trawls, operate in shallow areas, and likely a competition for space may if farming sites move towards traditional fishing areas. Potentially, there could also be competition for space between recreational fisheries, shipping, and energy (winds and tidal currents) and the aquaculture industry. An overall marine spatial plan for the coastal area including identification of marine areas that should be protected and the effect of multiple stressors is increasingly emergent with the increased activity.

The Environmental NGO Føroya Náttúru og Umhvørvisfelag (www.fnu.fo) has a high focus on the need to escalate the transition towards green energy, and the need to define protected and conservation areas. FNU have also protested in some of the licencing processes of marine site licencing and land use for smolt farms in regards to areas they consider should be protected. Monitoring the effects of fish farming on the seabed at local scale is a requirement from authorities (Chapter 5). Studies of nutrient and organic load and eutrophication are conducted in selected fjords and do not indicate substantial effects at regional scales (Chapter 6). However, research at ecosystem level is not sufficiently explored and more knowledge is needed. Considering the size of the fish farming industry, there is some concern among the public for potential effects on the health of the coastal ecosystems. The coastal region is a nursery area for several local fish stocks, such as cod, saithe, whiting, plaice and other. Consequently, there is some concern within the fishing sector whether the fish farming activity might affect recruitment to these fish stocks. Overall, there is a need for future research on the effect of fish farming on coastal ecosystems.

9 Future projections, and emerging threats and opportunities

9.1 Projections for salmon aquaculture

The factors limiting the growth of salmon aquaculture are largely environmental and biological. Salmon farming already occupies nearly all suitable locations for traditional farming in open net cages on the Faroese coastline. Further expansion will require innovations in farming methods to reduce environmental impacts or development of cage technologies allowing for movement offshore (Young *et al.*, 2019). Currently, salmon lice are a major obstacle for increased commercial production of Atlantic salmon, as the control of salmon lice at the various fish farms is a prerequisite for increase of biomass according to the legislation (Sea lice regulation, 2016). This was also reflected in the work conducted by an expert group appointed by the Faroese government in 2021 on Blue Growth. In the strategy report coming out from the process, there were no targets set with regards to the quantities to be produced, but that the export value of Faroese seafood products should be 11 billion DKK, an increase of 3 billion relative to 2020 (Løgmansskrivstovan, 2021). It was also explicitly mentioned that this would not come from increasing quanitites, but by increasing the value per kg raw material. The need for more research into sealice, fish welfare and new technologies for fish farming was also emphasised in the report.

In recent years, there have been large investments into research and development, as highlighted in previous chapters.All three salmon producing companies in the Faroe Islands are concentrating on growing larger smolts, which will spend less time at the sea to better utilize the limited number of sites and to reduce the risk of disease and sea lice infection. These investments into land-based facilities to produce larger smolts will, with all other things being equal, lead to a more efficient utilisation of the marine sites.

The salmon farming companies are also working towards production in highly exposed areas that are unsheltered from the forces of the North Atlantic. There is also concrete experimental work on semi-closed units in one of the fjords. If successful, these technological and process innovations will be game-changers with regards to future production. Closed systems will reduce the need for fallowing and the waste can be led out of the fjords, thereby allowing more intensive utilisation of the sites. Thereby, the innovations within the industry with regards to production systems will likely bring about changes to the legislative framework.

9.2 Diversification of the aquaculture industry

Aquaculture production in the Faroe Islands is largely dominated by salmon, and this is largely reflected in the legislation. Prior to 2019 the legislation only allowed single species farming in each of the 22 management areas, that all were occupied with salmon farming. This has been an obstacle to the development of other aquaculture industries, although a few experimental licences for seaweed farming have been active. The current aquaculture legislation has been changed and intentions are to open other areas for culturing of various species. In 2020, two permanent licences were allocated to two companies to farm macroalgae, with an additional site license allocated in 2021. One of the license holders farms *Saccharina latissima*. The other holds a licence to farm *Palmaria palamata*, *Porphyra umbilicalis*, *Saccharina latissima*, *Alaria esculenta* and *Laminaria digitata*, which all are native to the Faroe Islands. In addition to this, the legislation also allows for allocation of sites for other plant and animal species. To date there is no commercial farming of other species.

The projected cultivation of macroalgae for 2022 is 400 tonnes wet weight. The larger macroalgae producer Ocean Rainforest has ambitious plans to upscale this activity with plans to produce 6000 TWW in 2025. However, this is dependent on additional site licences. There are also concrete plans to allocate licences for shellfish production, most likely blue mussels. The report from the Blue Growth expert group called for the establishment of a suitable framework that could facilitate the development of shellfish and macroalgae production, and highlighted the need for a systematic analysis of appropriate sites for shellfish and macroalgae cultivation to facilitiate marine spatial planning (Løgmansskrivstovan, 2021). The Faroe Islands have an excellent environment for farming Atlantic salmon, and have a well consolidated and innovative salmon farming industry. This in combination with the ever-growing market demand for Atlantic salmon is the main driver for further growth.

9.3 Need for additional protein to feed the growing global population

There is a need for additional proteins to feed the growing global population. Aquaculture is expected to play a critical role in increasing food production and the demand for seafood is expected to increase. Aquaculture already supplies over half of the worlds seafood, and this figure is expected to increase to 60% within the next decade (FAO). Aquaculture growth has expanded the growth in any other livestock food sector (Little *et al.*, 2016). This presents a great opportunity for the aquaculture sector. It is also an important contributor to food security on the Faroe Islands. The quantities of salmon produced in the Faroe Islands far exceed what would ever be consumed by the population with over 4.6 kg of salmon produced per citizen a day, so naturally almost all of the salmon produced the the Faroe Islands is exported. However, salmon is widely consumed by the Faroese population, and is both available to purchase from the producers directly as well as in all supermarkets. There are no official figures on how much salmon is consumed by the population in the Faroe Islands. According to data from the salmon producers, 146 tonnes were sold on the Faroese market in 2021, providing an indication that on average each capita consumed 2.7 kg of Faroese salmon. Another indication of fish consumption can be found in a report published by the Faroese Board of Public Health (2021), which states that more than 61 % of the population eat 'fish' between daily to 1–2 times a week.

9.4 Sea lice and disease

The limitations for increased aquaculture production will likely be environmental and biological. In fact, disease is a primary threat of the continued growth due to extensive effects on the sector (Bjelland and Liu, 2014). The single largest threat to salmon production in the Faroe Islands is sea lice, which has also been the main driver of innovations in farm practices and production technologies.

The effects from sea lice on the fish welfare and the productivity of the aquaculture industry are multifaceted. Due to the treatment measures and management restrictions, sea lice rarely have direct serious impact on the health of the farmed salmon. However, the indirect effects are substantial. The treatments stress the salmon and result in reduced growth, increased susceptibility to diseases, and increased mortality (Bjelland and Liu, 2014). This also varies according to life stages as smolt in the grow-out stage are more vulnerable to sealice. As highlighted above, large investments have been made in order to produce larger smolts, thereby reducing the time at sea and consequently the sea lice problem. Continuous efforts are also being made with closed systems and moving further offshore.

9.5 The impact of climate change on marine aquaculture production

Anthropogenic climate change is already altering coastal and marine environments throughout the world at an unprecedented rate (IPCC, 2022; Scheffers *et al.*, 2016; Barange *et al.*, 2018; Falconer *et al.*, 2020). Aquaculture production will most certainly be impacted by climate change, affecting contributions to global food supply (Barange *et al.*, 2018).

Salmon production in the marine environment predominantly takes place in open net-pens, and it exposes the activity to several risks that can lead to production losses (Reid *et al.*, 2019; Pincinato *et al.*, 2021). As such, the production at an aquaculture site is affected by many different climate, biological, and environmental factors that can vary both spatially and temporally and even sites that are relatively close together can have very different conditions and farm practices (Falconer *et al.*, 2022).

The ways in which multiple stressors and their interactions will affect the industry is recognized as an area that needs attention to maintain or increase aquaculture production under climate change (Sará *et al.*, 2017; Falconer *et al.*, 2022). However, existing projections for the Northeast Atlantic have substantial uncertainties when applied to local fjords. There is a great need to systematically evaluate the impact of these projections on the aquaculture sector and to develop adaptation plans for the industry. Based on literature from neighbouring countries, such as Norway and the UK, it is apparent that the impacts from climate change will be multifaceted and will affect the industry through multiple stressors in a complex way (Reid *et al.*, 2019; Falconer *et al.*, 2022).

A range of climate factors affecting salmon production have been identified in the literature. These include: 1) sea level rise and extreme water levels, 2) increased intensity and frequency of storms 3) changes in air and/or sea temperature, 4) extreme temperatures and heatwaves, 5) ocean acidification, 6) deoxygenation, and 7) changes in precipitation/run-off (Falconer *et al.*, 2022). These climate stressors can have complex and profound implications for the aquaculture industry (see for instance Reid *et al.*, 2019 and Falconer *et al.*, 2022). For instance, temperature directly affects individual growth rates, whilst heatwaves can lead to reduced appetite resulting in slower growth and thermal stress. Increased temperatures and decreased oxygen levels are also known to stress salmon (Falconer *et al.*, 2022).

Seasonally, the seawater temperature in the mixed shelf water fluctuates between ~6 and ~11°C. The fluctuations are a bit higher in the stratified fjord systems (Figure 1.9) than in the mixed shelf water (Figure 9.1).

Long-term monitoring of the mixed shelf water temperature shows an increase of about 1°C during the last 100 years and the temperature rise was mainly during the period from the 1990s to the early 2000s (Figure 9.1). In general, the temperature is expected to increase further during this century, however, it is unlikely that the sea temperature in the Faroe Islands will increase beyond the thermal tolerance of salmon.

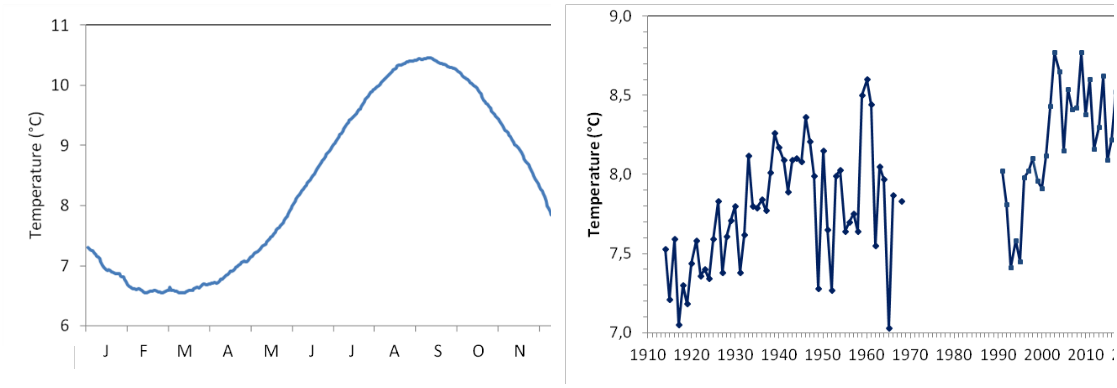

Figure 9.1 Daily mean temperature, 2010–2021 (left panel) and mean annual temperature of the mixed central shelf water, 1914–1969 and 1991–2021 (right panel). Source: Faroe Marine Research Institute.

Temperature will also affect the presence of pathogens and parasites; for instance, sea lice infection pressure is predicted to increase in future due to increased temperatures (Sandvik *et al.*, 2021). This implies that the problem and necessary treatments are exacerbated at higher temperature. Furthermore, the two most important risk factors for outbreak of Amoebic Gill Disease (AGD) are considered to be seawater temperatures and high salinity (Falconer *et al.*, 2022). Increasing temperatures are also likely to increase the risks for Harmful Algal Blooms (HAB) and jellyfish blooms.

Changes in precipitation and run-off from land, may have pronounced effects on stratification and seawater exchange in the fjords where the circulation is estuarine driven. This may alter the amount of production the sites may carry and the primary production and foodwebs in the fjords.

More frequent and intense storms are probably one of the larger concerns for the Faroe Islands. Storms create challenging conditions for salmon and they affect fish behaviour as fish adjust their position in cages in response to waves and currents (Johannesen *et al.*, 2022). Bad weather conditions and storms, resulting in high waves and fast current speeds can increase stress in salmon kept in sea cages (Solstrøm, 2017). Storms and high current speeds can also lead to wounds and fin damage due to collisions (Solstrøm, 2017). Extreme storms and waviness can also compromise human safety on sea. Consequently, extreme weather events also present operational challenges at the farms with periods with no human access to the sites.

Falconer *et al.* (2022) highlight in their analysis of Norwegian salmon aquaculture that multiple climate change stressors will occur together and frequently interact. It is therefore important to keep in mind that the interactions are synergistic, and which dominant driver may have the greatest effect depends on species and life stage. Another aspect to consider is that the different life stages of the farmed species each have specific biological requirements, different production technologies are used, and the farms are located in a range of varying environmental conditions. As a result, any consideration of the effects of climate change will have to take the local environmental conditions and practices into considerations. As such, it is essential to conduct a thorough analysis of the local effects that climate change can bring about. For that purpose, it is necessary to develop projections for Faroese fjords so that climate change adaptation plans for the aquaculture sector can be developed (Pham *et al.*, 2021).

9.6 Availability of feed and perceptions of sustainability

The challenges posed by climate change also relate to another important future challenge of the expanding aquaculture sector. Climate change will likely have implications for global fishmeal and fish oil supply (Reid *et al.*, 2019; Falconer *et al.*, 2022). As the cost of feed represents about 50% of the overall production costs (Iversen *et al.*, 2020) an increase in fishmeal prices, could affect production costs quite substantially. Added to that, is the challenge to ensure enough supply of feed ingredients for the growing aquaculture sector. This all has implications for sustainability, and the public acceptance of aquaculture practices. For instance, the issue of using wild-caught fish for aquaculture rather than human consumption is receiving increasing attention attention globally. Despite this general future challenge for aquaculture, Faroese feed producers are in a relatively strong position when it comes to availability of raw material. Situated centrally in the Northeast Atlantic with great access to marine resources, including the currently abundant blue whiting stocks largely used in fish feed, as well as access to the sidestreams from fish processing plants and long-distance demersal factory trawlers, means that there are large quantities of locally sourced marine raw material to be used in aquaculture.

Nevertheless, the reliaance on capture fisheries has also received some attention in the Faroese context, where analysis suggest that 1.8 kg of wild captured fish are required to produce 1 kg of salmon when using the feed produced in the Faroe Islands (Bogadóttir 2019). This figure takes into account that half of the marine raw material comes from cut-offs from fish processing, which would not have been used for human consumption. While some would argue that aquaculture has a great role to play in increasing global food production, others would argue – due to the reasons above - that it has detrimental effects on the world global fisheries (Kok *et al.*, 2020). Globally, there is increasing focus on the fish in: fish out ratio of the production, which has been reduced through increasing utilisation of terrestrial crop ingredients (Kok *et al.*, 2020). This in turn puts increasing pressure on land-based resources, and reduces the nutritional value of the fish (Sprague *et al.*, 2016). There are ongoing efforts to identify and develop novel high-quality feeds. Ingredients based on single cell proteins, such as algae, yeast and bacteria; insect meals and mesopelagic fish have started to enter the feed market (Kok *et al.*, 2020; Falconer *et al.*, 2022). Considering the Faroese aquaculture production, macroalgae could also be an interesting feed ingredient in future. It has been suggested that seaweeds contain several bioactive compounds in macroalgae that can benefit farmed finfish (Wan *et al.,* 2019). Developments with microalgae to produce omega-3 (EPA and DHA) could mitigate somewhat the use of fish oil in feed (Sprague *et al.*, 2017). There are continuous efforts to optimize feed usage though the use of technological developments as well as develop novel feeds from alternative proteins. Future developments on novel feed ingredients will be critical for the continuous sustainable growth of finfish aquaculture.

9.7 Knowledge gaps

Salmon farming	Knowledge gaps and data needs
Salmon lice impacts on wild salmonids	Stock assessment of the native trout *Salmo trutta* Behaviour and migration of trout Salmon lice infection levels on trout
Nutrient and solid waste emissions	Time-series of coastal water quality Time-series of benthic fauna that are unrelated to the specific aquaculture activity in consensus to the water framework directive
Zinc and copper	Effects on biota acceptable limits at the fish farms possible accumulation
Use of chemicals	Effects on non-targeted organisms Possible accumulation
Cleaner fish (lumpfish)	Escapes of cleaner fish Genetic introgression in wild lumpfish Disease transmission to wild fish populations
Aquaculture in general	Knowledge gaps and data needs
Spatial planning	Ecosystem based costal area management Identification of marine natural conservation areas Long-term plan for arrangement of multiple activities in coastal area
Seaweed and shellfish farming	Ecosystem effects from creation of new habitats Ecosystem effects from increased bivalve spawning
Commercial fish stocks	Basic knowledge of migration and behaviour of wild fish populations in near shore environments Importance of coastal habitats for fry
Climate change	Time-series Local projections of expected change
Public perception	Survey data on public perception and social acceptance of aquaculture
Labour marked	More detailed statistics about people on the labour market by sector (educational level, job title, salaries)
Economic statistics	Economic statistics on different stages of the supply chain (smolt farms, sea farms, harvesting and processing) Multiplier effects on other industries (input-output tables)

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Annex 1: List of participants

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Annex 2: Resolutions

2022/WK/ASG04 Workshop on the Faroes ecoregion Aquaculture Overview (WKFaroesAO) chaired by Gunnvør á Nordi, Faroe Islands, and Henn Ojaveer, ICES, will be established and meet (hybrid meeting) in Tórshavn, Faroe Islands during 31 May–2 June 2022 to:

a) Review and discuss the data and information collected for the Faroes 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 Faroes ecoregion aquaculture overview.

WKFaroesAO will report by 21 of October 2022 for the attention of the ACOM. The ADG will take place in early 2023.

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. The objectives AOs are to: i) synthesize regional and temporal information on aquaculture activities, practices and production of the cultured taxa; ii) consider environmental and socio-economic interactions of aquaculture activities and practices; iii) provide insights on cross-sectorial interactions of aquaculture; and, iv) consider future perspectives. Sections of the overview: 1) executive summary; 2) introduction; 3) description and location of marine aquaculture activities and practices; 4) production over time; 5) policy and legal foundation; 6) management frameworks; 7) ecosystem/environment interactions; 8) social and economic context; 9) interaction of environmental, economic and social drivers; and 10) future projections, and emerging threats and opportunities.
Resource requirements	The lead author of the Faroes ecoregion AO (Gunnvør á Nordi) 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 Faroes ecoregion AO, as well 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: Report of the Review Group for the ICES Report of the Workshop on the Faroes Ecoregion Aquaculture Overview (WKFaroesAO)

Note that the authors of the WKFaroesAO report provided responses to each reviewer comment. These responses are integrated throughout this Review Group report, each starting with the header, "**Response**".

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 Matthew Gubbins, Fisheries Data Programme Manager and UK Delegate to ICES Council, Marine Scotland Science
- Dr Francis O'Beirn, Section Manager–Licensing and Policy Advice, Marine Environment and Food Safety Services, Marine Institute, Ireland

The three members of the Review Group developed separate reviews of the proceedings of the Workshop on the Faroes Ecoregion Aquaculture Overview, and then discussed the report and their reviews virtually via Microsoft Teams on 20 January 2023. In particular, the reviewed report was to serve as the foundation for the ICES Faroes Ecoregion Aquaculture Overview and was to address the following points:

1. Summarize regional and temporal information on aquaculture activities, practices, and production of cultured taxa;
2. Describe the relevant policy and legal foundation;
3. Consider the environmental and socio-economic interactions of aquaculture activities and practices;
4. Provide insights on the interaction of environmental, economic, and social drivers;
5. 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 (ToRs) of the original report adequately met or addressed?

The reviewers agreed that the ToRs of the original report were generally adequately addressed, with the exception of: a) items raised within the 'Major Consistent Recommendations' presented on page 3 of this document and b) individual reviewer comments. Revision to the report responsive to these comments should result in a report that fully addresses the ToRs.

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.

Consensus was reached among the reviewers regarding the major points made within the separate reviews. 'Major Consistent Recommendations' are presented on page 3 of this document.

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)?

The reviewers agreed that scientific information presented was generally sound and clear, except for specific gap areas (see #4 below). Upon revision to address these gaps, the report would be a sound basis for the ADG to prepare ICES advice from. The reviewers acknowledge use of local references throughout the report, and inclusion of unique and valuable information relevant to the Faroes Ecoregion – for example, the discussion of the out planting of larger-sized smolt as an innovative approach to address production challenges.

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?

Certain gap areas were identified (e.g. social context/public perceptions of aquaculture) that warrant clarification and perhaps further discussion – please see the 'Major Consistent Recommendations' on page 3. In instances where information is not presented because it does not exist, text should be included in the report that states these gaps so that future work can address them. For gaps identified where information is available but has not yet been included, the reviewers ask the authors to include that information in this report.

Consensus Review Group Report – Major Consistent Recommendations

Below, the Review Group describe the major consistent recommendations across reviewers and refer the authors of the WKFaroesAO report to the individual reviewer reports below for more information.

Review: Section 1 warrants: a) greater linkage of background/environmental information with its relevance to aquaculture, and b) greater balance of information.

For example, in later sections (e.g. 6.) the impacts of aquaculture on nutrient dynamics are described. Some descriptive linkages within Section 1 would be useful. With regards to balance of information, Section 1 presents a full subsection on '1.2 - Seabirds and marine mammals', but the following subsection '1.3 - Central Shelf' encompasses broad elements of the full ecosystem (e.g. hydrography, phytoplankton, zooplankton).

Response: We agree that it might seem odd that seabirds take such prominence, and the subsections of the WKFaroesAO report (hereafter, the report) chapter 1 are now rearranged, such that seabirds and mammals are now in section 1.4 of the report. The original reason for positioning seabirds as the second section is that, due to the totally different conditions on the central shelf and fjords we have described them in separate subsections, but seabirds and mammals cover both of these areas.

More information on aquaculture impact on nutrients and primary production is added and also information on *Harmful Algal Blooms.*

"Fish farming is a primary source of anthropogenic nutrients to the fjords, and although this might influence the primary production, there is no long-term monitoring or modelling of the potential impact. The few measurements that can enlighten on potential eutrophication, do not show evident changes due to aquaculture.

The knowledge of harmful algae is scarce, as there is no national monitoring. All monitoring is conducted on request by fish farming companies and companies that export wild shellfish, and these data are not publicly available.

Mortality of farmed fish in relation to Harmful Algal Blooms are rare. Such mortalities have been observed in stratified fjords and straits, on five incidences since the onset of fish farming with the last two incidences occurring in 2006 and 2018. The algal species related to these mortalities were Alexandrium tamarense, Heterosigma akashiwo and Chrysochromolina (Eilif Gaard, personal communication)."

Review: Seaweed farming is described as an emergent sector throughout the document, but limited information is provided.

While this may be due to the nascent status of the sector, more information would be helpful—for example, who (i.e. are they the same companies as those farming salmon?), what (i.e. what species are being produced?), why (i.e. are they being produced for export markets? etc.). Sections 2 & 3 would be a good fit for this information, noting other locations in the document may also be appropriate (e.g. Section 9).

Response: More information has been added to the report sections 2 and 3. To emphasize that seaweed is not farmed by fish farm companies, the word other has been added:

> *"The salmon farming sites are operated by three companies while two other companies farm seaweed."*

A paragraph describing the species and method is also added to the report section 2:

> *"The seaweed species produced are primarily Saccharina latissima and Alaria esculenta. The two seaweed production companies have quite different production strategies. One farms on submerged horizontal longlines which are receded every year, and the other company has developed a Macro Algae Cultivation Rig (MARC) with vertical seed lines connected to a horizontal main line. This company also uses a partial harvest method with regrowth of the macroalgae from the same holdfast, avoiding the need for reseeding after each harvest (Bak et al. 2018)."*

A paragraph describing market is added to the report section 3:

> *"Most of the biomass is exported to European markets as food, food ingredients and feed additives for livestock. There is also some production for the local food market, and in addition seawed is produced for Lumpfish shelters in salmon farms, AkvaNest."*

Review: More information on production methods and history is needed (e.g. Sections 2 and 3).

Limited information is provided on the production methods used (e.g. gear). Incomplete history information is provided—for example, what was the extent of rainbow trout production up to 2010, and why did production of this species cease?

Response: The available statistics do not distinguish between rainbow trout and Atlantic salmon, and exact quantification of the extent of rainbow trout farming is not possible.

More information on the reasons behind the cease of rainbow trout farming has been added to section 3 of the report:

> *"The reason for the cease of Rainbow trout farming was the lower profitability compared to Atlantic salmon. The market price for Rainbow trout was lower, the feed conversion rate higher and there were larger issues of downgrading in quality due to sexual maturation at sea."*

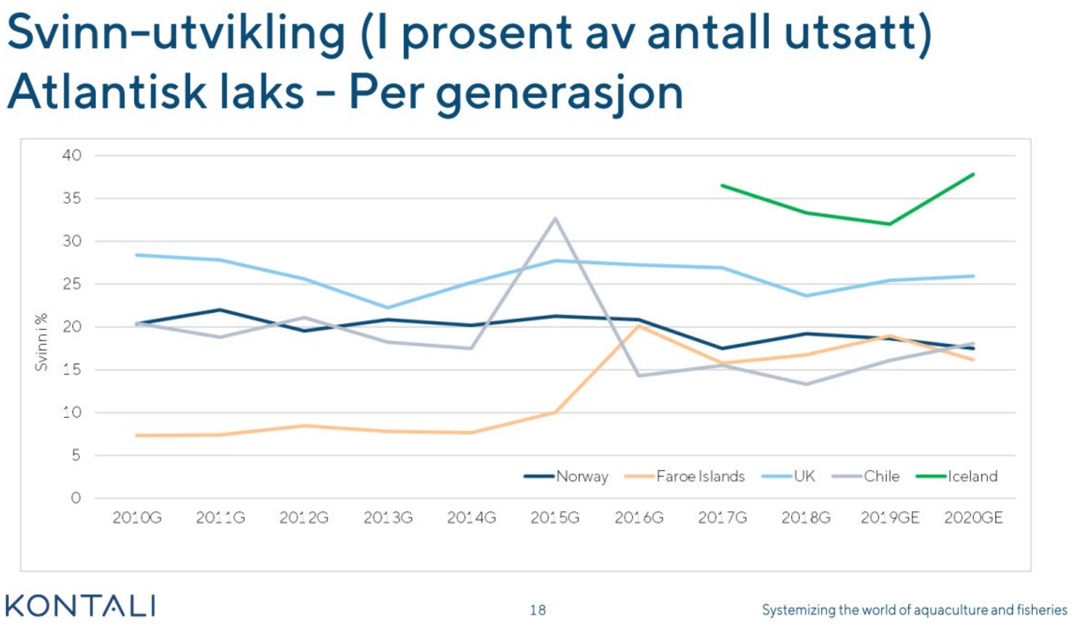
Review: Mortality information in Section 3 (e.g. Figure 3.4) indicates a long-term mortality rate ~15%, warranting comparison with production in other locations.

Please include information that places the mortality rate in the context of similar information for salmon production in other locations. This would help the reader to understand if the relative mortality rate in the Faroes Ecoregion is higher, lower, or comparable to similar levels in other locations. This may involve a brief summary of the information presented in Nystøyl, 2022. At a minimum, the reference to the source of mortality data for the Faroes Ecoregion is warranted.

Response: Kontali has this comparison between Norway, Faroes, UK, Chile and Iceland (Nystøy, 2022). Actual values behind the graph referred to are not available.

A section has been added to the report describing the graph below in more detail:

"According to Nystøyl (2022) the mortality in Faroe Islands was between 5 and 10% from 2010 to 2014, while it was around 20% in Norway and Chile, and even higher in UK. But from 2016 to 2020, the mortality in Norway and the Faroe Islands was between 15 and 20% in both countries. Mortalities in Chile have been quite fluctuating. In 2015 it was above 30% but from 2016 to 2019 it was somewhat lower than in Norway and Faroe Islands."



The data presented in figure 3.4 is from Avrik, as described in the figure text.

Review: Conditions described for existing aquaculture sites in the Faroes Islands meet criteria for 'offshore' aquaculture (e.g. SWH up to 4m, current speeds > 80 cm/s).

The report provides some description of plans for growth of 'offshore' aquaculture, but a definition is never provided while described conditions for the existing aquaculture sector already meet literature-based definitions of offshore aquaculture. Describe gear/equipment being used to withstand the conditions being used, and any considerations around fish welfare.

Response: It is now stated in the report, that some of the farms already are in offshore conditions according to Froehlich et al. 2017, the reference Dr Seth Theuerkauf provided:

> *"to coastal sites exposed to ocean swells with measured significant wave heights (H_{m0}) up to 4 m (Abrahamsen and Patursson, 2017) or tidal currents up to 80 cm s^{-1}(Klebert et al., 2015). Such exposed conditions are considered offshore, even though the distance to shore is quite short (Froehlich et al. 2017). The potential of farming further out on the Faroe shelf are currently being investigated."*

And a section with a brief description of gear at exposed sites has been added:

"The rough conditions at exposed sites sets high demand for gear, especially mooring systems, and although the gear essentially looks the same as in sheltered location, with floating circular net pens, the gear is modified and tailored for the exact conditions at the sites (e.g. www.vonin.com/product/moorings)."

Review: Section 4 includes limited details on: a) licensing processes, b) environmental regulations, and c) environmental/effluent monitoring conditions.

Greater detail should be included in these areas. For example, for licensing processes, what are the major issues, if any, that are present during licensing consultations?

Response: Substantially more information is now provided on the licensing processes, environmental approvals and monitoring.

Added to the report section 4.1:

"FFVA sets upper limits from sea lice counts as described in 5.1.2 as well as from other health and welfare parameters such as mortality rate. When assessing approvals of production plans the FEA looks at a variety of factors and approvals are based on an individual estimate in each case. For example, the results of seabed surveys, production- and feed amount in the previous cycles is considered, as well as any new or changed operational measures."

Licencing processes

For new licenses the FFVA must first determine which fjords and aquaculture species will be offered in a licensing round. Then there is a licensing round with information on which fjords and species there can be applied for. The applicants must hand the application in on the application form, that is made for the licensing round. Included in the application there has to be a map, showing the exact limited area for the planned activity.

When the application is received, it is sent for consultation to relevant public authorities, municipalities and other parties involved.

After the consultation, the in-house processing of the applications according to the legislation contains that approval must be granted by the FEA, the Faroese Veterinary Authority and the Faroese Food Authority.

Other considerations are:

- *The applicant´s interests*
- *Possible conflicts of interest, regarding:*
    - *Use of the area*
    - *Other aquaculture activity*
    - *Conservation area*
    - *City plans*
    - *Governmental plans for activity on the fiords*

Depending on the demanded granted approvals and reading of the issue in general, a license can be approved for a maximum of 12 years with possibility for renewal.

Specified in a licence is species, biological stage (broodstock, smolt, fish), water/sea, location (cadastral number or ocean coordinates) license and validity period. Note that no quantity and/or biomass is in the license, as this is processed in the operation plans (See section 5 of the report).

As the license term draws to an end, the licensee can apply for a renewal of the given license. The process for applications for renewal of licenses is similar to the process of applications for new licences, except that there is no need for a licensing round.

During the license validity period the licensee can apply for changes in the license regarding the location.

Major issues during the licensing process the last 10 years have mainly been conflicts of interest regarding the applicant's need for the applied location vs. other use of the area such as lobster fishing. Other issues have arisen the past years in connection with the relocation of breeding sites. For the farming industry in the Faroe Islands to grow, it has been necessary to move the breeding sites from the more protected fjords to more exposed areas. The more exposed areas place greater demands on the aquaculture installment."

Text added to section 4.2 of the report:

"The exact conditions vary a bit between newer and older environmental approvals, but there are general conditions about, noise, smell, feed, waste, seabed surveys etc. There are limit values for noise, but there are no quantitative limits on feed, biomass, effluents, medicines etc. This is partly controlled through the approval of production plans for the individual farming cycles."

Text added to section 5.2 of the report:

"Seabed surveys include two types of tests, i.e. simple assessment and chemical analysis. The simple assessment is an assessment of the seabed condition carried out immediately after sampling. It encompasses four assessment categories:

I. *simple fauna assessment: are animals larger than 1 mm present in sample?*

II. *pH and redox potential in the top cm of the sample,*

III. *sensory assessment: evaluation of bubbles, colour, odour, texture and sludge thickness.*

IV. *Photos of all samples*

The chemical analysis includes testing for copper and zinc contents in sediment, as well as for organic material measured as loss on ignition.

The result from the simple assessment for each sample is calculated in accordance with annex 2, 3, 4 and 5 in the Guidance, 19/2018, which gives a value that equates to a score for the condition of the environment.

Significant levels of pollution detected at farming sites or signs of pollution outside farming sites are indications that pollution levels are higher than the farming site tolerates. Fish farming operators are required to manage aquaculture in a manner that prevents pollution from reaching unacceptable levels. If significant levels of pollution are detected, fish farm operators must adapt their practices to ensure that pollution returns to acceptable levels."

Review: Greater detail regarding the social context and public perceptions of aquaculture in the Faroes Islands is warranted. Section 7 provides great information on the economic context of aquaculture in the Faroes Islands, and some amount of social context can be derived (e.g. labor market information). But, there is a gap in description of the social backdrop of aquaculture – is it well supported by communities? Are public perceptions positive, neutral, or negative? Is the public involved in the licensing process (e.g. Section 8)? Are environmental non-profits active in the Faroes (e.g. relevant to Sections 7, 8, and 9)?

Response: A short section on public perception (Section 7.4) has been added to the report. There is very limited information available, and it is highlighted specifically as a knowledge gap which needs to be filled.

"The public commonly associates aquaculture with both positive and negative effects for the public which vary greatly depending on the specific contexts (Alexander et al., 2016; Hynes et al., 2018; Cantillo et al., 2023). It is seen as an economic benefit and a critical source of employment in coastal regions and important for food security. Some of the negative aspects relates to harmful environmental impacts.

There is no published literature in the Faroe Islands focusing on the public's acceptance of aquaculture. There are, however, no indications that suggest any general public resistance to aquaculture operations. There are no environmental NGOs present in the Faroe Islands which oppose aquaculture development. However, a survey sponsored by Føroya Nátturu og Umhvørvisfelag (FNU, 2022), with 500 respondents from the general public, showed that 67 % of respondents 'agreed' that the aquaculture industry should be subject to stricter environmental regulations. This indicates that there might be some 'silent' environmental concern regarding the activity. The lack of research concerning the public perceptions towards aquaculture is a major knowledge gap, and presents a critical data gap with respect to the ability to assess the social sustainability of the sector."

Review: Future projections described in Section 9 are fairly general/global, and more Faroes Islands-specific information would be beneficial.

For example, Section 9.3 provides global context on the need for aquaculture to provide protein—however, the specific Faroes Island context is not provided. Does aquaculture contribute directly to local food supplies and food security or are the benefits derived primarily economic? Is it expected to play a greater role in the future? What is driving the existing aquaculture sector, and its possible future growth (e.g. industry-driven, government initiatives)?

Response: Here efforts have been made to relate this specifically to the outlook in the Faroe Islands. In section 9.1 of the report, reference has been made to a strategy document on Blue Growth. In section 9.2 of the report, the plans for increased macroalgae production have been briefly clarified, to address a comment below. And the need for the establishment of creating the conditions for macroalgae and shellfish aquaculture, as highlighted by the Blue Growth Strategy. In section 9.3, the topic of food security has been briefly elaborated, with some information of the salmon consumption in the Faroe Islands. Again, here there are no official statistics to support the section, but we have collected the information from the aquaculture producers.

Text added to section 9.1 of the report:

"This was also reflected in the work conducted by an expert group appointed by the Faroese government in 2021 on Blue Growth. In the strategy report coming out from the process, there were no targets set with regards to the quantities to be produced, but that the export value of Faroese seafood products should be 11 billion DKK, an increase of 3 billion relative to 2020 (Løgmansskrivstovan, 2021). It was also explicitly mentioned that this would not come from increasing quantities, but by increasing the value per kg raw material. The need for more research into sea lice, fish welfare and new technologies for fish farming was also emphasised in the report."

Text added to section 9.2 of the report:

"The larger macroalgae producer Ocean Rainforest has ambitious plans to upscale this activity with plans to produce 6000 TWW in 2025. However, this is dependent on additional site licences. There are also concrete plans to allocate licences for shellfish production, most likely blue mussels. The report from the Blue Growth expert group called for the establishment of a suitable framework that could facilitate the development of shellfish and macroalgae production, and highlighted the need for a systematic analysis of appropriate sites for shellfish and macroalgae cultivation to facilitate marine spatial planning (Løgmansskrivstovan, 2021)."

Text added to section 9.3 of the report:

"It is also an important contributor to food security on the Faroe Islands. The quantities of salmon produced in the Faroe Islands far exceed what would ever be consumed by the population with over 4.6 kg of salmon produced per citizen a day, so naturally almost all of the salmon produced the Faroe Islands is exported. However, salmon is widely consumed by the Faroese population, and is both available to purchase from the producers directly as well as in all supermarkets. There are no official figures on how much salmon is consumed by the population in the Faroe Islands. According to data from the salmon producers, 146 tonnes were sold on the Faroese market in 2021, providing an indication that on average each capita consumed 2.7 kg of Faroese salmon. Another indication of fish consumption can be found in a report published by the Faroese Board of Public Health (2021), which states that more than 61% of the population eat 'fish' between daily to 1–2 times a week."

Individual Reviewer Reports from the Three Reviewers:

Review by Dr Seth Theuerkauf (Review Group Lead)

Big picture comments

- Seaweed farming is described as an emergent sector, but limited information is provided. While this may be due to the nascent status of the sector, more information would be helpful—for example, who (i.e. are they the same companies as those farming salmon?), what (i.e. what species are being produced?), why (i.e. are they being produced for export markets, etc.). Sections 2 and 3 would be a good fit for this information.

Response: More information has been added to sections 2 and 3 of the report. See Response to the second bullet point under Major Consistent Recommendations.

- Section 7 provides a great deal of information on the economic context of aquaculture in the Faroes Islands, and some information on the social context by way of the labour market. However, there is a social dimension that is missing—is the aquaculture sector well supported by communities? Are perceptions positive, neutral, or negative? Is there any social science literature that can be drawn upon?

Response: A short section on public perception (see section 7.4 of the report) has been added. See the seventh bullet point under *Major Consistent Recommendations*. There is very limited information available, and it is highlighted specifically as a knowledge gap which needs to be filled.

- What is driving the existing aquaculture sector, and its possible future growth? Is it all industry-driven, are there government initiatives (e.g. strategic plans), etc.?

Response: The growth and the technological developments within the industry are exclusively industry driven.

General Comment:

- There are minor cases where grammar is imperfect. These are likely largely addressed in Reviewer Francis O'Beirn's tracked changes, but I recommend a copy-edit of the full document.

Specific Comments:

- *Executive Summary, final paragraph* – Surely there are existing climate change projections for the Faroes Islands that could be further resolved/researched to estimate potential impacts on the sector. I suggest re-wording to indicate this as a research gap or need (i.e. evaluating the impact of projected climate change on the Faroes ecoregion's aquaculture sector).

Response: The paragraph has been changed and now focus on the knowledge gap on expected impacts of climate change on the Faroese aquaculture industry.

"There are significant uncertainties related to the effect of climate change on the sector. Evaluating the expected impacts of climate change on the Faroese aquaculture industry should therefore be prioritized and is a prerequisite to enabling the development of climate change adaptation plans for the sector".

- *Section 1.2* Are interactions between seabirds, marine mammals, and the aquaculture sector a concern? If so, or if not, this section would benefit from 1-2 sentences introducing those interactions.

Response: A sentence introducing interactions has been added: "Interactions between seabirds and aquaculture are mostly bird entanglement in bird nets and in some areas seals, that prey on farmed fish is an issue."

- *Section 1.2* 'altogether 20% of the world's marine mammals have been observed in the ecoregion' – is this referring to 20% of all known species, or literally 20% of total biomass? I am presuming 20% of all known species, but this is important to clarify.

Response: This is now clarified. The sentence now reads: "-altogether 20% of all known mammal species have been observed in the ecoregion".

- *Section 1.3, Hydrography* Are there concerns that water retention on the central shelf may also affect dispersion of effluents and lead to eutrophication? Impacts on sea lice retention are described. If nutrient impacts are a concern, please list them.

Response: At the scale of the central shelf there is no concern about nutrient impacts from aquaculture. This has been investigated in the long-term nitrate winter concentration of the mixed shelf water. In Fjords there is concern about eutrophication, but there are no long-term dataseries to address this and the few investigations that can enlighten on the problem do not show evident changes due to aquaculture. This is addressed in section 6.1 of the report.

- *Section 1.3, Phytoplankton* Are there existing concerns regarding harmful algal blooms?

Response: There are no concerns on the scale of the central shelf, but on the scale of fjords this is an issue. The knowledge of HAB is added the section describing conditions in fjord and straits.

See Response to the first bullet point under *Major Consistent Recommendations*.

- *Section 1.3, Fish* Are the causative agents of declines known, and can they be briefly described here? Overfishing, environmental changes, etc?

Response: High fishing mortality is assumed to be due to one reason, "The reason behind the observed variability in recruitment, seems to be the high fishing mortality, causing foodweb instability between food production and food demand (ICES, 2022)."

- *Section 1.4, Primary production and nutrients* To what degree are the observed patterns natural processesvs.highly influenced by anthropogenic inputs (e.g. salmon farming)? For example, diminished dissolved oxygen conditions are described in certain fjords, stagnant bottom water is described in certain areas. Are these conditions purely based on the natural physical environmental conditions, or are they exacerbated by anthropogenic inputs (e.g. nutrients from wastewater, agriculture, or aquaculture)? Some brief description would be helpful.
- Section 6.1 describes fish farming as a primary source of anthropogenic nutrients and further provides some discussion on interactions between aquaculture-derived nutrients and primary production. At a minimum, it would help in Section 1.4 to have a few sentences introducing these aquaculture-environment interactions related to nutrients.

Response: A section introducing the potential eutrophication and lack of long-term monitoring was added to the report:

"Fish farming is primary source of anthropogenic nutrients to the fjords, and although this might influence the primary production, there is no long-term monitoring or modelling of the potential impact. The few measurements that can enlighten on potential eutrophication do not show evident changes due to aquaculture."

- *Section 2, Page 12* Is the reduction in sea lice infection the main driver for moving further out of fjords, or are there other reasons, too (e.g. effluent dispersion)? It would help to explain fully.

Response: Yes, effluent dispersion is also a factor. The sentence has been changed to, "Farming areas have been gradually moved further out on the fjords where currents are stronger, internal infection with sea lice lower, and the effluent dispersion is higher."

- *Section 2, Page 12* When were the seaweed sites permitted?

Response: This information has been now added to section 2 of the report*: "Seaweed farming started on trial basis in 2010 at sites allocated to salmon farms. The first two permanent sites for seaweed farming were allocated in 2020 and a third macrofauna farming site was allocated in 2021."*

- *Section 2, Page 13* What is the breakdown in amounts of ova imported vs. domestically produced?

Response: More details on domestically produced ova has been added*: "Ova were produced in the Faroe Islands until 2017. From 2018 to 2021 all ova were imported. However, a work is going on with Faroese broodstock and in 2022 13% of the ova were domestically produced".*

- *Section 2, Page 13* It may fit better in the 'Future Directions' section, but I was looking for more information on the growth of offshore aquaculture. The conditions described (SWH up to 4 m, tidal currents up to 80 cm/s are substantial) are considered 'offshore' (see Froehlich et al. 2017 in Frontiers in Marine Science - Offshore Aquaculture: I Know It When I See It). A single sentence is provided on page 13. Can any more be said here?

Response: Thank you for the reference. There is not much public information on the plans for farming further offshore, so it is difficult to elaborate much more on that. More information is added to the section. See respond to the fifth bullet point under *Major Consistent Recommendations*.

- *Section 3, Page 15* More detail on the lack of growth in rainbow trout farming is warranted.

Response: The only reason given by the farming companies for quitting rainbow trout, has been profitability. Rainbow Trout has lower market price, higher FCR and larger issues with downgrading in quality due to sexual maturity in sea. On the positive site, Rainbow Trout is more disease and lice resistant, but this was not deemed important enough versus the cons.

More information was added to the report. See the third bullet point under Major Consistent Recommendations.

- *Section 3, Page 15* Do you mean to say 'small scale'? 160 tonnes is a great start, but not a lot.

Response: The last sentence has been removed.

- *Section 4.1.* What information is used to set the upper limits for production by FFVA and FEA? Do they use models to look at effluent impacts? Sea lice counts (e.g. the Traffic Light System in Norway)?

Response: Information on the limits for production has been added:

" FFVA sets upper limits from sea lice counts as described in 5.1.2 as well as from other health and welfare parameters such as mortality rate. A variety of factors are considered by the FEA when assessing production plans for the upcoming production cycle, these include the results from the seabed surveys, the biomass production and feed amount in previous production cycles as well as any changes in the operation plans for the upcoming production cycle."

- *Section 5.1.1.* 'The location of a sea farm shall not have a considerable effect on spreading diseases.' – Is this what the regulations state, or a general principle, or both? It would help to be clear.

Response: The regulation specifies distance between farms to prevent transmission of diseases.

"The biosecurity regulation lays down minimum distances between aquaculture activities. In one fjord multiple species can be farmed as long as they are at different trophic levels, e.g. one fjord may have one finfish species, one shellfish species and one seaweed farm."

- *Section 5.1.2* Please clarify that the limit for salmon lice is based on an average, if that is the case. What is the average of? The entire farm? It is also stated earlier that sea lice counts are done by an independent third party. Can you clarify this here, and explain further? Is that a regulatory requirement?

Response: The limit is based on a weighted average based on sea lice counts and fish count in all net pens.

"According to the sea lice regulation it is mandatory to report the infestation level of salmon lice at each location at least every 14 days to FFVA. The regulation stipulates how the sea lice counts are to be performed, including that fish from all cages at the location (20 fish from each cage) shall represent the counting and that the sea lice infection at each site is reported as the weighted average with regard to the number of fish in each cage. Furthermore, the regulation stipulates that the counting has to be performed by the independent company, Fiskaaling. Lice infestation and use of pharmaceuticals at each locality are published at FFVA´s homepage."

- *Section 5.2* Is environmental monitoring required to be conducted by a third party, too?

Response: Yes, only laboratories approved by FEA for the assignment can conduct the monitoring.

"According to the environmental licences, surveys are to be conducted by a laboratory preapproved by the FEA, and thus the surveys are conducted by a third party."

- Section 6.7 Are marine mammal entanglements a concern? Are interactions regulated?

Response: *"Although there is a ban on lethal control, accidental mortalities such as entanglement may still occur, and such incidents must be registered. According to Havbúnaðarfelagið, no marine mammal mortalities have occurred since January 2021 (Seafoodwatch, 2022)."*

- *Section 6*.8 – What seaweed species are being farmed? What methods? More detail would be helpful. This information is presented in 9.2 – it should be moved up higher.

Response: More information on species, methods and market is added to section 2 and 3. See Response to the second bullet point in Major Consistent Recommendations.

- *Section 7* It is presumed that most salmon is exported. Is any retained locally? Is it an important food source? Does it contribute to food security?

Response: This has now been addressed in section 9.3 of the report. See respond to the last bullet point under Major Consistent Recommendations.

- *Section 8, Page 40* It would help to define who the major stakeholders are in the Faroes Islands, even if just by grouping.

Response: A list of stakeholders has been added to the report, "these are coastal fishers, land-owners, environmental NGOs, local communities and citizen groups."

- *Section 9*.3 This information is not unique to the Faroes Islands. It would be helpful to replace it with any local context on how aquaculture supports local food security (if it actually does).

Response: Food security and salmon consumption are briefly discussed in section 9.3 of the report. See Response to the last bullet point under Major Consistent Recommendations.

Review by Dr Matthew Gubbins (Review Group member)

Overall, I find this Aquaculture Overview very well written, well presented and informative. As such it largely addresses the Terms of Reference put to the Workshop. The Faroese Aquaculture Overview is fairly unique in that the sector is single species, single administration with an excellent track record of data collection and availability. As a result, the report as it pertains to salmon farming is thorough and pretty comprehensive.

Areas that seem to be missing or relatively weak are the production methods (missing for salmon farming and seaweed) and any real detail (beyond site number and production) on seaweed farming. There are 6 sites potentially producing a few hundred tonnes but we are in the dark as to species produced, environmental impacts, legislation (beyond being on the side of a salmon farming licence), biosecurity, market etc., etc.

Much of section 9 is also rather generic (global) in focus on aquaculture projections rather than Faroes-focused. There is an excellent synthesis of knowledge gaps at the end.

<u>**Specific comments:**</u>

- Executive Summary Page ii Query the lack of climate change predictions for Faroes ecoregion?

Response: The paragraph has been changed to: “There are significant uncertainties related to the effect of climate change on the sector. Evaluating the expected impacts of climate change on the Faroese aquaculture industry should therefore be prioritized and is a prerequisite to enabling the development of climate change adaptation plans for the sector”.

- Page 2 section 1.2 Why do birds and marine mammals take such prominence compared to other ecological factors or receptors?

Response: We agree that it might seem odd that seabirds take such prominence, and the subsections of chapter 1 of the report are now rearranged, such that seabirds and mammals are now section 1.4.

- Section 1.2 penultimate line. 20% of the worlds marine mammal species.

Response: This is now clarified, “-altogether 20% of all known mammal species have been observed in the ecoregion”.

- Section 1 In general the background information on the Faroes marine ecosystem as a location and receiving environment for aquaculture and its pressures is useful, detailed and relevant. But more effort could be made to relate the significance of the content to aquaculture e.g. primary production, plankton, nutrients etc.

Response: Information on nutrients, potential eutrophication and Harmful Algal Blooms has been added: See Response to the first bullet point under Major Consistent Recommendations.

- Section 2 page 13, Fig 2.2. Individual farm production biomass is useful information for the review but so is maximum standing biomass. The 2 are related by production and harvesting plans and the environmental impacts arising from salmonid culture are often relative to either parameter.

Response: A graph has been added to Figure 2.2 describing the biomass and fish count at sea. It would probably fit better as a separate figure, but in order not to change the figure numbers of the current draft this solution was chosen. A section describing the standing biomass has also been added.

"The standing biomass and total number of farmed fish at sea have been fairly stable during the last 7 years (Figure 2.2), with total fish count at sea around 20,000,000 individuals while the standing biomass has varied between 40,000 and 62,000 tonnes, depending on the timing of the individual farming cycles."

- Page 13 Paragraph 1 – Of note tidal currents of 80cm/s and 4m significant wave heights would make for extremely challenging farming conditions using the equipment in operation at these sites?

Response: A section with a brief description of gear at exposed sites has been added. See Response to the fifth bullet point under Major Consistent Recommendations.

- Page 13 Paragraph 2 – Where are the broodstock facilities producing ova in the Faroes mentioned. Not detailed elsewhere in the report? Is this a gap?

Response: Information on the Faroese broodstock has been added, "The broodstock in the Faroe Islands, is maintained on land in freshwater and seawater facilities to minimize the risk of diseases."

- Page 14 cleaner fish. Find it hard to believe many of the wrasse species used elsewhere in NE Atlantic are not native to Faroes.

Response: Wrasse species of interest as cleaner fish are not native to the Faroe Islands which is also the case for northern Norway, where like in the Faroes they only use Lumpfish.

"In 2014 when the first cleaner fish were imported, there was a concern of importing non-native species that might disturb the ecosystem. The wrasse species of interest at that time are non-native to Faroe Islands, which limits the species to lumpfish (Cyclopterus lumpus)."

- Page 15 What species and cultivation method for seaweed at the three farms referred to?

Response: Information on species and cultivation methods is added to section 2 of the report. See Response to the second bullet point under Major Consistent Recommendations.

- Page 16 section 3.1 Line 1&3 – Effectiveness, line 2 conversion

Response: I am not sure, what the reviewer refers to here. The change that is made is that feeding effectivity is changed to feeding effectiveness.

- Page 18 section 4.1 throughout "Licence"

Response: This word has been replaced throughout the section.

- Page 19 section 4.2 Would be usefult o know what the environmental approval from FEA conditions are? i.e. does it control feed, biomass, effluent, medicines etc in terms of quantities.

Response: More information is provided:

"The exact conditions vary a bit between newer and older environmental approvals, but there are general conditions about, noise, smell, feed, waste, seabed surveys etc. There are limit values for noise, but there are no quantitative limits on feed, biomass, effluents, medicines etc. This is partly controlled through the approval of production plans for the individual farming cycles".

- Page 20 section 5.1.1 paragraph 3 "basis"

Response: OK.

- Section 5.1.1 – Any actions related to invasive non-native species rather than pathogens?

Response: Some regulations that are not directly related to aquaculture are in place to prevent invasive marine species, e.g. the regulations on ballast water, that state that this should be treated or dumped at least 200 nautical miles from shore.

- Page 22 Section 5.2. Sea bed pollution is assessed only on the basis of these 3 variables? Fig 6.2 suggests also redox potential?

Response: Substantial more information is added to section 5.2 of the report, including parameters for seabed surveys.

"Seabed surveys include two types of tests, i.e. simple assessment and chemical analysis. The simple assessment is an assessment of the seabed condition carried out immediately after sampling. It encompasses four assessment categories:

V. simple fauna assessment: are animals larger than 1 mm present in sample?
VI. pH and redox potential in the top cm of the sample,
VII. sensory assessment: evaluation of bubbles, colour, odour, texture and sludge thickness.
VIII. Photos of all samples

The chemical analysis includes testing for copper and zinc contents in sediment, as well as for organic material measured as loss on ignition."

and

"Significant levels of pollution detected at farming sites or signs of pollution outside farming sites are indications that pollution levels are higher than the farming site tolerates. Fish farming operators are required to manage aquaculture in a manner that prevents pollution from reaching unacceptable levels. If significant levels of pollution are detected, fish farm operators must adapt their practices to ensure that pollution returns to acceptable levels."

- 5.3 Any entanglements reported?

Response: No entanglements of mammals have been reported since 2021, this is now written in section 6.7. The text below is added to section 5.3:

"Registrations of possible accidental killings due to entanglement are mandatory."

- Page 27 section 6.4. What is the purpose of the liver colour scoring index referred to? Are lumpfish used across production cycles or removed with the salmon at the end of the production period to avoid acting as a disease reservoir?

Response: Information on how the lumpfish is used has been added:

"All the fish farming companies use lumpfish as cleaner fish to some degree, and the welfare is regularly monitored, resulting among others in the development of a liver colour scoring index as a measure of health and welfare condition (Eliasen et al., 2020). It is against the legislation to transfer lumpfish between sites and production cycles. After each completed production cycle the lumpfish thus are removed and destroyed to prevent disease transfer."

- Page 29 section 6.8 Reader is still in the dark as to which species of seaweed are farmed and how?

Response: Information on species and gear has been added to section 2 and 3 of the report, and a sentence on species also added to this section.

"Today it is mostly Saccharina latissima and Alaria esculenta are farmed, but other local species are also tested."

- Page 37 section 7.3 define what the contribution to the public sector from aquaculture referred to derives from?

Response: Here we have clarified the effect on the public sector, and added further details where the ripple effects stem from.

"There are no recent surveys of the multiplier effects, but a survey from 2015 indicates a direct multiplier of around two in aquaculture, indicating that around 16% of the total GDP originates directly and indirectly from aquaculture. Two thirds of this effect stem from purchases of goods and services within the industry, whilst the remaining third originate from the ripple effects from the employees' consumption. In addition to this, the survey showed that there are additional effects from the fact that the aquaculture industry is financing a part of the public sector, and historically, a growth in public revenues from the aquaculture sector has always led to increased public spending. The increased public spending then brings the total multiplier up to around three, indicating that the aquaculture sector is the source of around 24% or a quarter of the total economy (Laksáfoss, 2015)."

- P42 section 9.2 We learn here of the species licensed for cultivation, but what has been the breakdown of species actually cultivated, ratios etc. Are all these species native to the Faroes?

Response: There are no available statistics on the exact breakdown of the cultivated species. It is only allowed to farm native species and the information is added to this section of the report.

"One of the licence holders farms Saccharina latissima. The other holds a licence to farm Palmaria palamata, Porphyra umbilicalis, Saccharina latissima, Alaria esculenta and Laminaria digitata, which all are native to the Faroe Islands."

- Section 9.2 paragraph 2 "Dependent on additional site licences"

Response: OK.

- Page 44 section 9.5 penultimate paragraph "Harmful Algal Blooms"

Response: OK.

- Page 45 paragraph 2 section 9.5 But those projections of environmental conditions exist (IPCC etc although admittedly with high uncertainties) and the production methods and species affected are known? So I am not sure I agree with this point. Does the work just need to be done to relate environmental change to impacts on production, environmental effects health and welfare etc?

Response: The paragraph has been changed to, *"However, existing projections for the Northeast Atlantic have substantial uncertainties when applied to local fjords. There is a great need to systematically evaluate the impact of these projections on the aquaculture sector and to develop adaptation plans for the industry."*

- Section 9.6 I agree entirely, but how does this relate to the ecoregion overall assessment?

Response: We have added additional information in Section 9.1, 9.2 and 9.3 to relate it more specifically to the Faroe Islands. See Response to the last bullet point under Major Consistent Recommendations.

Review by Dr Francis O'Beirn (Review Group member)

Note: An annotated version of the Workshop Report was provided by Dr O'Beirn, which including many detailed edits in track changes. Many of these edits are captured below in the comments from Dr O'Beirn in addition to some additional minor grammar and punctuation issues that were also addressed in the report. As such, this annotated version of the Workshop Report is not included as an appendix to this reviewer report.

- **Section 1 –** this section gives a general description of the physical characteristics of the Ecoregion divided according to specific regions. They are well presented and detailed. The importance of the region for seabirds and mammals is also acknowledged. It would be important that clarification regarding the reference to "20% of the world's marine mammals" relates to the proportion of species or overall abundance. I imagine it's the former.

Response: The 20% relate to proportion of species. This is now clarified, *"Several other species have been observed and altogether 20% of all known mammal species have been observed in the ecoregion (Fossaa et al., 2006)."*

- The use of locally derived references are important. The reference to benthic data and diversity in Fjords might be supported by the presentation of some summary data. For example, presentation of the summary statistics of diversity when compared to similar systems in Norway UK and Denmark. Any reasons for any differences observed might also be provided?

Response: The benthic data comparison between countries is not an intercalibration as in e.g. Borja et al. 2007 Marine Pollution Bulletin 55 (2007) 42–52, as we have calculated the indexes for the various countries on samples from reference stations in the Faroe Islands. The methods behind the indexes is highly variable between countries and thus a presentation of summary statistics would be too time consuming for this deadline and we suggest to postpone that to the next revision of the WKFaroesAO.

- The reference to brown trout is important. How many of these present as sea trout and are there some catchments considered more important for having sea-trout that others?

Response: The knowledge of brown trout is really sporadic. There are no stock assessment of brown trout and no assessments on how large portion is in lakes without connection to the sea, nor are there areas identified more important than others. The only regulation in regards to trout is that it is not allowed to fish in rivers some time of the year and that it is not allowed to fertilize land within a certain distance from rivers.

- **Section 2** The description of aquaculture production is simplified by the culture of one species of culture. The historical context is clearly communicated as is the evolution of the sector from many small-scale operators to more consolidated ventures with higher production. What would be useful would be an indication on the average size (in hectares) and range of the size of the licenced areas of farms. IN addition, production information partitioned according to sheltered versus exposed sites?

Response: A figure is added to figure 21 showing the size variability of farming sites and more text is added.

" Today 35 sites are allocated for Atlantic salmon farming and three sites are allocated to seaweed farming, and the areas are highly variable in size (Figure 2.1). There is no obvious relation between size of areas and exposure nor the production and size since permitted production is regulated by biological and environmental performance at the individual sites (see section 5)."

- The reference to offshore farming is somewhat confused without specific definitions - some might argue that those coastal sites with 4m swell and 80cms-1 currents might be considered offshore? I recommend clarifying definition of 'offshore'.

Response: Dr Seth Theuerkauf also pointed out the offshore conditions and guided us towards the paper by Froehlich et al. 2017. Rather than defining the limits for offshore farming, we have added a sentence to point out that the conditions are considered offshore. See respond to the fifth bullet point in Major Consistent Recommendations.

- The presentation of Figure 2.3 is important. This represents a significant piece of information and should probably be subject to follow on discussion. I would refer specifically to the reduction in production time identified in Fig 2.3. What has the survival been of these larger 'smolts'? Reference to Thermal Growth Coefficient (TGC) later in the document might offer some insight?

Response: A table is added showing the growth and survival rate at sea grouped by smolt size at sea transfer, and a text is added describing the differences between small and large smolt.

"The only difference in performance at sea by smolt that are large at transfer to sea compared to small smolt is the shorter duration of the farming cycle at sea. This was also the purpose of increasing the smolt size. The large smolt also show better growth performance (Table 2.1)."

- The reference to cleaner fish is also important. It would be important to clarify if the fish sourced from outside the ecoregion are sourced from wild-caught or hatchery or both? Also, are there other native species used as cleaner fish or with potential?

Response: The only species used as cleaner fish is Lumpfish, and there is no ongoing research to test other species. The imported cleaner fish mostly origins form wild-caught fish that is stripped at on land facilities where the roes are hatched and fish is grown. More information on the cleaner fish is added to the report.

" Lumpfish for use in the salmon farming industry are imported from Iceland and Wales and there is also some production in the Faroe Islands. The cleaner fish mostly origins form wild-caught fish that is stripped at on land facilities where the roes are hatched and the fish is grown to the desirable size."

- **Section 3** This section is short and it seems, focuses primarily on Atlantic salmon production. It would be useful to know the extent of rainbow trout production up to 2010 and why this species production ceased?

Response: The statistics did not distinguish between rainbow trout and Atlantic salmon, and exact quantification of the extent of rainbow trout farming is unavailable. See the third bullet point in the report under Major Consistent Recommendations.

- The framework for aquaculture is presumably summarised in Jacobsen (2011). However, would it be possible to elaborate on the nature of the framework in this report and how it addressed the disease issues and subsequently resulted in an increase in production, or perhaps make reference to the fact that it will be discussed further in the document?

Response: A brief summary on the regulations is added.

"The most revolutionary change was that only one year class was allowed at each farming site with mandatory fallowing between year classes. Detailed regulations to the daily operations at the fish farms to prevent disease transfer were formulated. e.g. monitoring for diseases and daily collection of dead fish with immediate silage. Stricter regulations in the case of disease outbreaks were also formulated."

- In relation to performance of salmon, it would be useful to future elaborate between the significance of FCRbio and FCReco? Furthermore, in Figure 3.3 the spike in 2018 suggests a large mortality – to what was this attributed?

Response: The growth performance was lower during summer 2018 than in other years, as the fish appetite was lower, the main reason for this is most probably algal blooms. More information has been added on the difference between FCReco and FCRbio:

"After the introduction of mechanical and thermal sea lice treatments the economic feed conversion ratio increased, while the biological feed conversion rate decreased, the increasing difference between FCReco and FCRbio reflects the increasing biomass loss before harvest (Figure 3.3)."

- Reference to mortality rates being comparable with Norway would be helped by the presentation of the actual values for both countries.

Response: Kontali has this comparison between Norway, Faroes, UK, Chile and Iceland (Nystøy, 2022). See Response to the fourth bullet point under Major Consistent Recommendations.

- **Section 4** This section is relatively clearly presented. However, it lacks detail as to how an operator might apply for a licence to operate. How many permits are required and what details must the operator provide to the relevant authorities? It would be useful to note (as indicated above) if licences refer to spatial extent and if so, what are the mean extent of a licence area? Furthermore, the limitations on (overall) production (re: ownership) are presented as 50% of the maximum. It might be clarified if this relates to the absolute number of licences or the levels of production, i.e. > 50% of production not permitted to one company?

Response: More information is added. See Response to the sixth bullet point under Major Consistent Recommendations.

- The term 'highly polluting activities' seems to be a somewhat pejorative phrase. It might be clarified if this is a specific/formal term and is it applied typically to finfish farming? If not, I would suggest the correct term be used.

Response: The term is translated from the heading of chapter 5 of the report in the environmental protection act. It can also be translated to particularly polluting activities. To emphasize that it is not only used for aquaculture activity, the first sentence of section 4.2 has been changed to:

"Aquaculture production, as well as practically all industry that utilizes resources and/or produces waste, is on the list of particularly polluting activities according to chapter 5 in the environmental protection act (1988)".

- **Section 5** – The biosecurity measure communicated and summarised in this section might be presented in bulleted form?

Response: The section is now in bullet form:

"Biosecurity regulations

- *The location of a sea farm shall not have a considerable effect on spreading of diseases.*
- *Distance to other aquaculture activities is emphasized in the approval of locations*
- *Production type, methods and amounts of production are considered*

- *The operators at fish farms are responsible for laying out a risk bases for internal control*
- *The internal control includes identification, description of risks of mortality, introduction and spread of diseases, escapes etc., training of staff and a contingency plan*
- *Each location has to have a land base where personnel change clothes, equipment is disinfected and dead fish is ensiled*
- *Equipment has to be disinfected before movement between sites*
- *The Faroe Islands are divided into management areas, typically on the scale of fjords*
- *There is only one-year class allowed in each management area, and there is a legislated fallowing period between production cycles*
- *During well boat transport, valves have to be close*
- *Dead fish has to be removed, minced and ensiled to PH 3,7 at least five days a week*
- *Veterinarian control is carried out 6–12 times a year, depending on the size of farm*
- *ISA surveillance is performed four times a year at each farm."*

- In term of single generations (year-class) within management areas (fjords), would it be permissible to move stock from a similar year-class into one area from another?

Response: No, it is prohibited by the biosecurity regulations.

- The term 'co-decisive' is used in Section 5.1.2. I'm unsure what this means.

Response: It was referring to the fact that it is not only sea lice management that is decisive for the allowed production. The paragraph has been rephrased:

"Thus, an important factor in the decision for the allowed production at the sites, are the number of lice and pharmaceutical treatments. Production sites with several exceedances of the limits for salmon lice and/or several pharmaceutical treatments have to reduce the number of fish. On the other hand, it is possible to increase the number of smolts if sea lice are well controlled at the farm."

- There is very little reference, or details provided, in the report to the types and scope of pharmaceutical treatments used to treat lice and diseases in salmon farming. This is an important omission and should be introduced in this section, even if it is referenced later.

Response: More time is needed to address this question.

- It is not clear if pharmaceuticals are monitored under the environmental monitoring programme?

Response: Pharmaceuticals are not currently part of the environmental monitoring program.

- Also, it would be useful to clarify if there are standards applying to the sampling and analysis under the monitoring programmes? Are they carried out by independent contractors or by the farms or by Government agencies? It would be important to identify the level of independence applying to the sampling and analysis.

Response: More information has been provided on the national guidelines and international standards,*"The guidance also specifies the international quality standards ISO and NS to be used for sampling and assessments."*

And on the requirements for the company performing the monitoring, *"According to the environmental licenses, surveys are to be conducted by a laboratory preapproved by the FEA, and thus the surveys are conducted by a third party."*

- In relation to marine mammals – is mortality from seals considered a major problem to salmon production?

Response: At some sites mortality from seals is an issue, however, we do not know the extent of the problem.

- **Section 6** In order to put the increase in feed in context it might be useful to overlay the production statistic (by year) on the feed use in Figure 6.1.

Response: In such a figure the term production would be math/model based, and not an actual value, since the actual biomass is only measured at harvest. This is the reason that such figures generally are not presented when production performances are presented.

- The reference to the lack of benthic monitoring post-2014 is confusing - fauna was used in monitoring up to 2014, but not since? The reason for not currently using it, as a monitoring tool, is the lack of expertise on local fauna? Does this mean that there are no experts in the Faroes to carry out the identification of infauna? However, the following paragraph identifies that the ASC is being used to develop a WFD monitoring using benthos infuana. Is there not a conflict here? Can these data be used for statutory aquaculture monitoring?

Response: It is not lack of local expertise in macrofauna identification that caused the FEA to stop requiring macrofauna monitoring. The reason was that macrofauna was not used in the decision making at site surveys due to lack of background information, i.e. no national classification system based on diversity indexes were developed and there was no consensus on which indexes, and boundaries should be used in the lack of background information.

This is clarified in the revised text:

"However, fauna has not been a part of the national evaluation of the environmental status due to lack of consensus on which foreign benthic quality indexes and classification system should be used, given that no national classification system was developed."

- The reference to sea lice as an issue is not entirely clear. It appears from the section 6.3 that it is managed solely to prevent harm to farm stock and minimise transfer to other farm units. In section 6.6, interaction with sea trout are considered. While it is early in the monitoring programmes, it should be clarified if there are concerns relating to wider ecological interactions. Do the authors consider that the levels of lice on farms present a risk to sea-trout stocks?

Response: It is quite possible that lice present a risk to sea-trout stocks, but data collection on sea trout is still in its early stages and there is no historic data from before fish farming, so at this stage any statement would be a pure guess.

- Seabird interactions – I bring the authors attention to the most recent Seafood watch report which presents fewer than 1 bird loss per site up to 2021. The reference to congregation of storm petrel at farm sites is interesting and might be worth discussing further?

Response: Thank you for the reference, this information is added to the report. Regarding the storm petrel, this is just a small study, and there is little material to discuss this further. However, it would be highly interesting to see more research on that.

"In 2021 an average of 2.1 bird mortalities were recorded per site (Seafood watch, 2021), adding to 53 bird mortalities in total assuming that the number of active sits was 25."

- The reference to shellfish farming is noted. It should be clarified that there are impacts from suspended shellfish farming that are considered negative, in particular in areas considered more sheltered or depositional. This should be acknowledged by the authors.

Response: Thank you for pointing this out. The following has been added to the report, *"However, there are also negative impacts from suspended shellfish farming, such as deterioration of the seabed below the farm due to increased deposition of organic matter (McKindsey et al., 2011)."*

- **Section 7** The short introduction reads very well. The term 'motivated limitations' in Section 7.1, is confusing. I wonder does it relate to the, rate of issuance of new licences?

Response: This has been rephrased, *"For the same reason, concerns for diseases have historically been the limiting factor to increases in production."*

- A definition of the term price premium would be helpful. I assume it refers to the higher price Faroes operators acquire when compared with, say, Norwegian prices per unit of salmon? What factors govern this premium? Quality, quantity?? ??

Response: It is very difficult to determine specifically what factors are most important with regards to the price premium. We have defined the term price premium:

"… price premium, i.e. a higher price compared to the benchmark price".

And we added a phrase with potential factors:

"Other potential influencing factors are the exclusivity associated with the Faroe Islands and superior quality."

- Figure 7.7 is very informative; it would be useful to include, on the horizontal axis, the months as they relate to lice infection.

Response: The timeline represents time since the smolt were transferred to sea. This is now clarified in the figure text. It is not possible to show this comparison with a seasonal timeline since the smolt were not stocked in the same month of the respective years.

- The socio-economic information is well presented and there appears to be good statistics broken down according to regions within the country. I'm curious about the focus on non-Faroes workers in the industry. Are the figures higher than other sectors? Also, from where do these workers mostly originate?

Response: The focus on non-Faroese workers is due to the higher prevalence of foreign workers in fish processing and aquaculture: *"This is substantially higher than that in industry other than fisheries and aquaculture where the corresponding figure is about 13 %."*

And details on where they originate were also added: *"Overall, about 80% of non-Faroese workers within aquaculture come from countries outside Europe (Statistics* Faroe Islands)."

- **Section 8** There is reference here to the ripple effect of fish farming on other industries and sectors. Is there any quantification of this in terms of wider economic indicators?

Response: Some more details have been added within section 7.3 of the report with regards to the origins of the ripple effects.

- The reference to benthic monitoring is identified as a legal requirement. How does this marry with the fact that monitoring does not appear to have been carried out since 2014?

Response: There is a misunderstanding here. The FEA dropped requirements for benthic macrofauna sampling in 2014, but monitoring of seabed conditions according to the guidelines described in section 5 still continue.

- The reference in the last paragraph to public concerns regarding environmental harm appears to the be the first such reference in the document. It would be useful to clarify the extent of public participation during the licencing process? Are there Environmental NGOs active in the Faroes and if so, what are the issues they might raise?

Response: *"The Environmental NGO Føroya Náttúru og Umhvørvisfelag (www.fnu.fo) has a high focus on the need to escalate the transition towards green energy, and the need to define protected and conservation areas. FNU have also protested in some of the licencing processes of marine site licencing and land use for smolt farms in regards to* areas they consider should be protected."

- **Section 9** This section is somewhat generic in its content and presentation. I don't have a lot to offer here, but I think it would be very helpful if the authors could refer to either government led or industry plans to guide future development of the industry? Are there national policy frameworks to direct future growth of the sector? The reference to future projections for seaweed culture suggests such plans might exist.

Response: See comment above in the major consistent recommendations. We have added additional information in Section 9.1, 9.2 and 9.3 to relate it more specifically to the Faroe Islands.

- Calls for diversification of the industry should be developed further - who raises this as an issue, is there really and appetite for IMTO among the salmon farmers?

Response: This has been developed further through the inclusion of a government strategy document. However, we have not elaborated on IMTA, as there was no specific focus on IMTA within the report. In the Faroe Islands, a 'regional IMTA' is currently more relevant, where several producers are placed within the same fjord, but not in an integrated system.