# WORKSHOP ON THE NORWEGIAN SEA AQUACULTURE OVERVIEW (WKNORAO)

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# Contents

# i Executive summary

ICES work on aquaculture is part of a wider portfolio of work that seeks to advance and share scientific understanding of marine ecosystems and the services they provide, and to use this knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals. ICES has decided to establish aquaculture overviews, which will: i) summarize regional and temporal information on aquaculture activities, practices, and production of the cultured taxa; ii) describe the relevant policy and legal foundation; iii) consider the environmental and socio-economic interactions of aquaculture activities and practices; iv) provide insights on the interaction of environmental, economic, and social drivers; and v) consider future projections and emerging threats and opportunities.

The Workshop on Norwegian Sea Aquaculture Overview (WKNORAO) was established to assemble and synthesize the data and information for the Norwegian Sea ecoregion aquaculture overview, identify the gaps and agree on the next steps to complete the draft overview.

The aquaculture activity in the ecoregion is currently only located along the coast, but there are initiatives also for offshore aquaculture. The total aquaculture production in the ecoregion was over 700 thousand tonnes in 2019. The main species were Atlantic salmon (96.8%) and rainbow trout (2.8%), both farmed with grow-out in open-net cages. The production of Atlantic salmon has more than tripled over the last 20 years. Other cultured taxa include sea trout, Atlantic halibut, Atlantic cod, Arctic char, as well as molluscs, crustaceans and echinoderms.

The central legal instrument for aquaculture in Norway is the Aquaculture Act, with an overall objective ’to promote the profitability and competitiveness of the aquaculture industry within the framework of sustainable development and contribute to the creation of value on the coast’. Management of aquaculture involves authorities at all levels, from local to national, and public hearings. The ’traffic light system’ was established in 2017 to regulate the growth of salmonid aquaculture based on the industry’s environmental impacts so-called ’production zones’ along the coast.

In addition to sea lice, genetic introgression by escaped farmed salmon and disease transmissions from salmon farms are considered as main threats to wild salmon. Other environmental threats include emissions of dissolved nutrients, particulate organic matter, pollutants and therapeutants.

The profitability of the aquaculture industry has varied over time, with very high values recently. The total employment in the industry is not very large, but it provides jobs to rural areas that have had a relatively poor population development.

Development of the aquaculture sector requires the inclusion of new production concepts for farming Atlantic salmon both on land, in closed/semi-closed pens in coastal waters and offshore and expanding or starting farming of other species. Together with applying integrated ecosystem assessment/management and considering the effects of climate change, this requires close attention in future.

# ii Expert group information

| | |
|---|---|
| **Expert group name** | Workshop on the Norwegian Sea Aquaculture Overview (WKNORAO) |
| **Expert group cycle** | Annual |
| **Year cycle started** | 2021 |
| **Reporting year in cycle** | 1/1 |
| **Chairs** | Terje Svåsand, Norway |
| | Henn Ojaveer, ICES |
| **Meeting venue and dates** | 23–25 March 2021, online meeting, (12 participants) |

# 1 Introduction

## 1.1 Location

The Norwegian Sea is situated between six other ecoregions and it is divided into international waters and the Norwegian Exclusive Economic Zone (EEZ) (Ottersen *et al.*, 2011; ICES, 2019). Relevant areas for existing inshore and considered offshore aquaculture are on the Norwegian continental shelf (hereafter shelf; Albretsen *et al.*, 2019; Norwegian Directorate of Fisheries, 2019). The ecoregion incorporates the coastal regions from Møre at about 62° N to Vestfjorden at about 68° N and borders the Greater North Sea along the 62°N latitude to the south (MCE, 2009) to the north (Figure 1.1). The emphasis here will therefore be on the shelf and coastal areas along the Norwegian coast as limited in the text above, in contrast to the ICES Ecosystem Overview for the Norwegian Sea ecoregion (ICES, 2021) putting equal weight on areas throughout the domain.

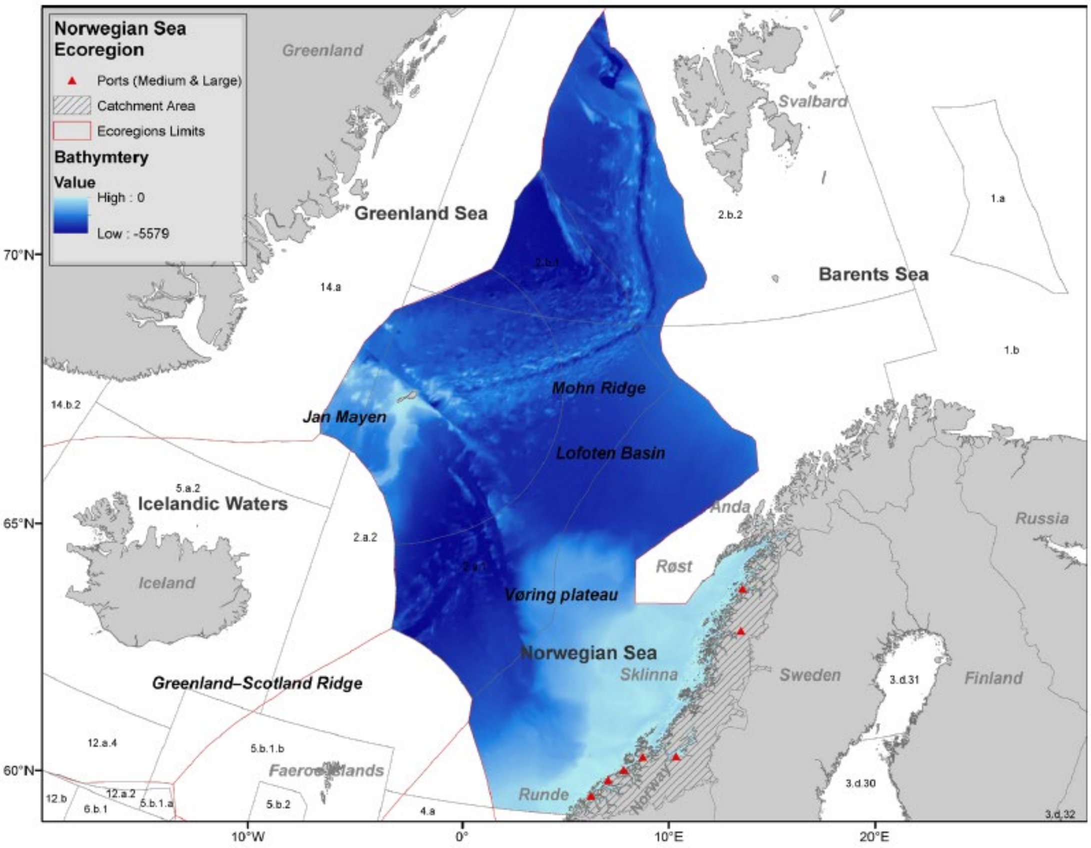

**Figure 1.1. The Norwegian Sea ecoregion limits, ICES areas, catchment area, and depth gradient (ICES, 2021).**

## 1.2 Topography

The ecoregion consists of two deep oceans with the Lofoten Basin to the north (about 3000 m) and the Norwegian Basin to the south (about 4000 m) in addition to intermediate and shallow areas including parts of the Norwegian shelf (ICES, 2019). The width of the shelf varies largely, from about 10 km to 260 km, and typical depths between 100–300 m. It is composed of both great plains and alternate shallow banks and deep trenches that harbour nutrient-rich and biodiverse ecosystems such as Røstrevet, the world’s largest cold-water coral reef (Sundahl *et al.*, 2020). The seabed of the banks is characterized by moraine, rocks and gravel, while that of the trenches is dominated by fine-grained sediments and mud. The trenches are a result of glacial erosion, and some of them extend into the fjords (Sundby *et al.*, 2013). The edge of the shelf constitutes a sharp transition from the shallow coastal areas to the deep waters of the ecoregion. It is marked by a steep slope from about 300 m to depths of several thousand meters. Due to topographically steered currents, the edge acts as a barrier for biogeochemical open ocean–shelf exchange.

The composition of most Norwegian fjords involves a sill at the fjord entrance, which regulates the horizontal movement of water masses between the coast and the fjord (Figure 1.2). Dense oceanic water must pass this barrier to replenish the oxygen content in the deep section of the fjord. This process seems to weaken (Aksnes *et al.*, 2019) driven by ocean warming and less dense water outside the sill.

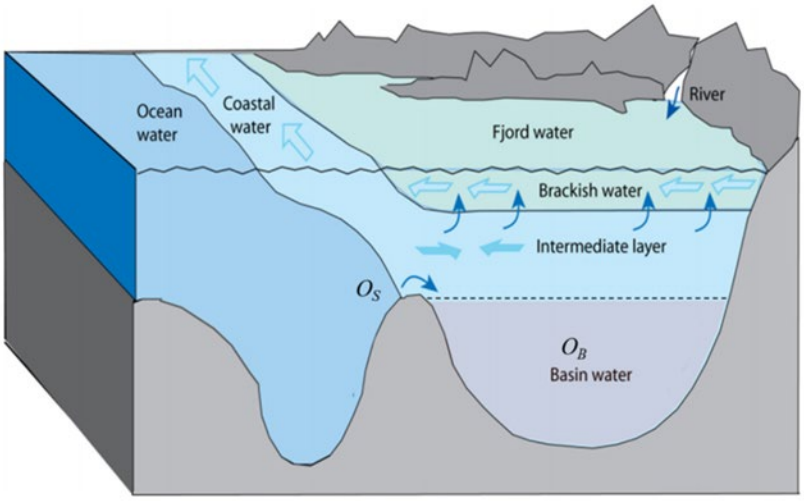

**Figure 1.2. Typical circulation features and water mass composition from the fjord head across the sill and towards the shelf and the open ocean. Source: Aksnes *et al.* (2019).**

## 1.3 Currents

The principal currents of the ecoregion are the saline two-branched Norwegian Atlantic Current (NwAC); the branch associated with the Subarctic Front in the west entitled the Front Current (NwAFC) and the branch located just seaward of the shelf break entitled the slope current (NwASC) (Figure 1.3). The other main current located trapped at the shelf is the fresh Norwegian Coastal Current (NCC). The bottom topography has a considerable impact on their circulation patterns, but their strengths, widths and vertical extensions are also influenced by atmospheric variability, and especially winds, river-run-off and tide. As a result of the generally stronger windforcing during winter, the NwASC and the NCC are strongest in winter and are at their weakest during summer (Sundby *et al.*, 2013; Orvik *et al.*, 2001; Skagseth *et al.*, 2011).

The NwASC brings warm saline water from the Atlantic Ocean northward along the edge of the shelf at an average velocity of 30 cm/s and a flux of about 4 Sv (Orvik *et al.*, 2001). Whirls developed in the NwASC and these frequently extends onto the shelf especially associated with the many trenches penetrating the shelf. The NCC has its origin in the North Sea and the Baltic and is fuelled by freshwater run-off along the coast. It flows northwards as a shallower (50–100 m) wedge-shaped current trapped by the shelf break and the Norwegian coast (Albretsen *et al.*, 2011). Typical current velocities are on the order of 10–35 cm/s, and though the water temperatures vary more than the in the adjacent NwASC, it is still less saline. As the Atlantic current is steered by the shelf edge, so is the NCC influenced by the bathymetry of the shelf. Thus, the banks and trenches are dominated by clockwise circulation over the banks and anticlockwise currents over the trenches. About 10% of the Norwegian coastal current enters Vestfjorden on the eastern side and exits along Lofoten, occasionally causing clockwise or anticlockwise movement in the middle of the fjord (Sundby *et al.*, 2013).

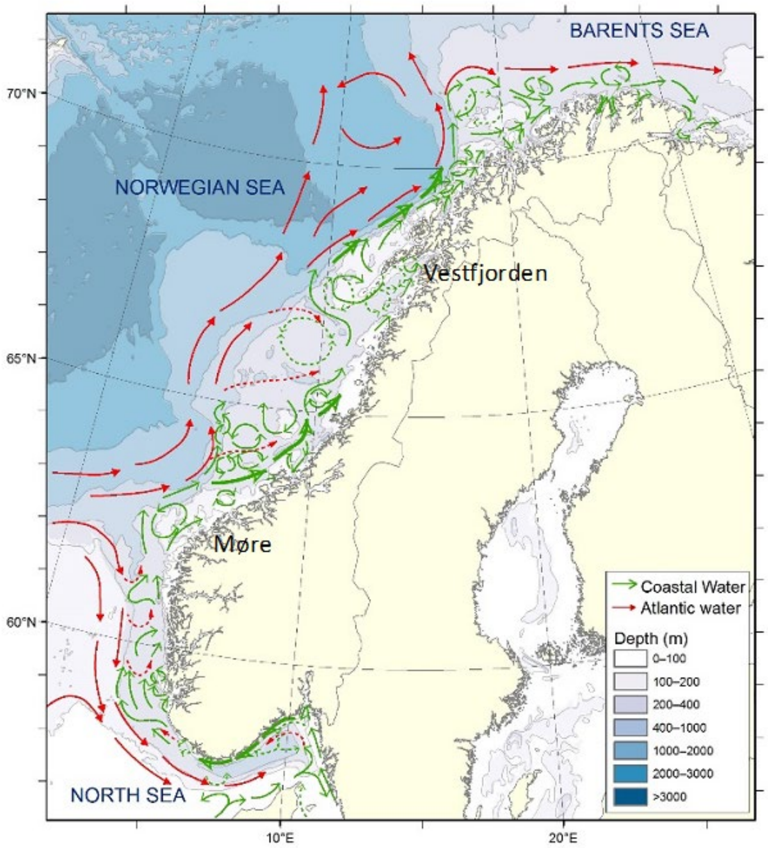

**Figure 1.3. Bathymetric map showing the movements of the Atlantic water (red arrows) and the coastal water (green arrows). Source: Ådlandsvik (2019); map by K. Gjertsen/R. Sætre at Institute of Marine Research-IMR.**

## 1.4 Spring bloom

The ecoregion is characterized as a spring-bloom ecosystem with considerable seasonal variability. It is driven by the annual fluctuation in sunlight as well as the nutrient availability and stabilization of the water column. During winter, strong winds create a vertical mixture, bringing nutrients from the deeper layers up into the top layer. When it becomes lighter in March, the photosynthetic activity of the phytoplankton in the photic zone intensifies. This leads to an algal bloom, i.e. a dramatic increase in phytoplankton productivity, reaching approximately one million algae per litre. As the algae consume key nutrients in the primary production (nitrogen, phosphorus and silicon), the bloom results in a concomitant nutrient depletion in the upper part of the water column, inhibiting its own activity. By May-June (delay towards the north), the production is thus decreased to a much lower level but display a secondary peak before almost coming to an end during winter (Sundby *et al.*, 2013).

## 1.5 Production zones for aquaculture

The Norwegian coast is divided into 13 aquaculture PZs (PZ) to provide a better foundation for management decisions (Figure 1.4, Section 4. Policy and legal foundation). They apply to Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). PZ 5–9 cover most of the coastal part of the Norwegian Sea ecoregion, except for a small area that belongs to PZ 4, while PZ 9 also covers the outer part of the Lofoten area which is a part of the

Barents Sea ecoregion (Figure 1.1 and Figure 1.4). The PZs are defined in a manner that minimizes the potential of salmon lice spreading across zonal borders, while also maximizing the coherence of each PZ, i.e. equal conditions within each zone (Ådlandsvik, 2015). The underlying method for the delineation is an influence matrix that estimates the probability of salmon lice spreading from one facility to another (Ådlandsvik, 2015), relying in part on the NorKyst800 model system (Albretsen *et al.*, 2011; Sandvik *et al.*, 2020; Asplin *et al.*, 2020). Thus, the exchange of salmon lice within a zone may be substantial, but the spread to facilities situated in other zones is kept to a minimum. In some cases, the boundaries between the PZs follow landscape features that naturally break up the inter-facility connectivity (Ådlandsvik, 2015).

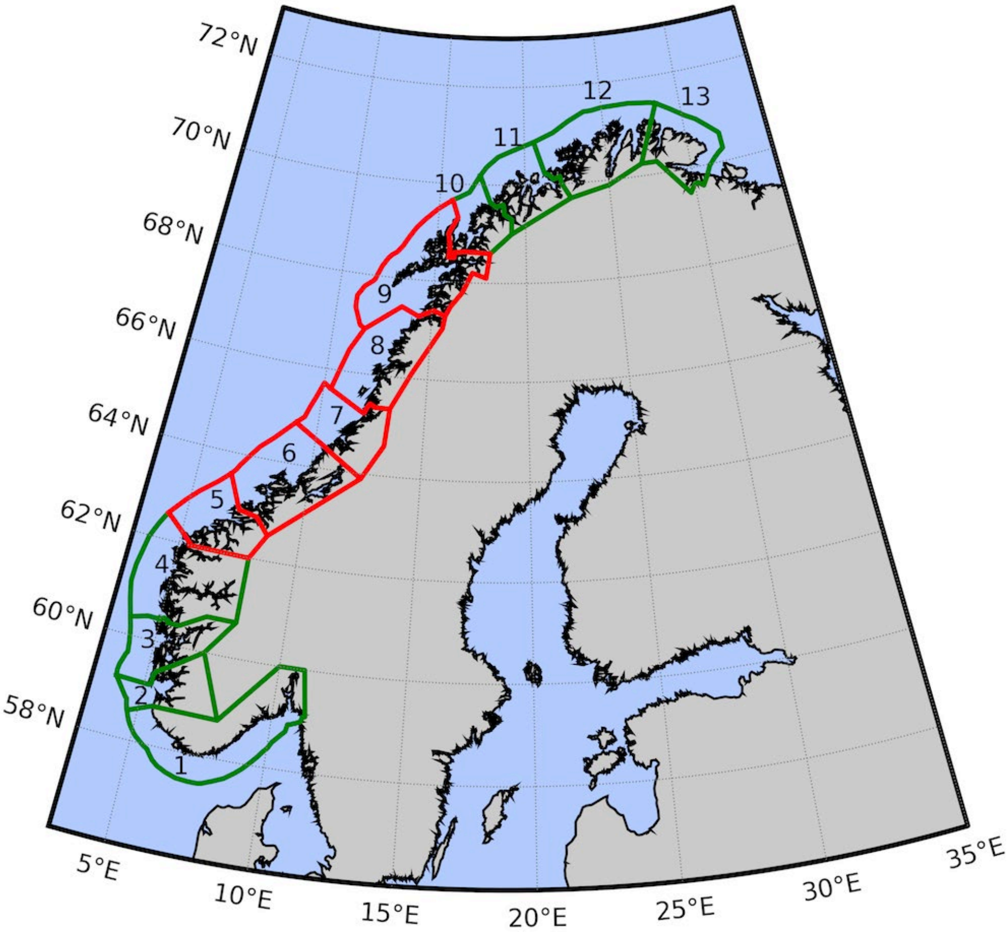

**Figure 1.4. Location of 13 PZs for Atlantic salmon, sea trout and rainbow trout in Norway. The PZs within the Norwegian Sea ecoregion are shown in red. The names of the PZs are the following: 5–Stadt to Hustadvika, 6–Nordmøre and Sør-Trøndelag, 7–Nord-Trøndelag and Bindal, 8–Helgeland to Bodø, and 9–Vestfjorden and Vesterålen). Modified from: (https://lovdata.no/dokument/SF/forskrift/2017-01-16-61).**

The Norwegian Sea management plan of 2009 (MCE, 2009) identified 12 particularly valuable and vulnerable areas (PVAs) in the Norwegian Sea ecoregion. One of their defining characteristics is their significance to the biodiversity and biological production within and beyond them, and the goal is that their integrity remains intact regardless of human activities. The coastal zone is a PVA. It is plentiful in species and ecosystems, and it performs important ecological functions (MCE, 2017).

# 2 Description and location of marine aquaculture activities and practices

The Norwegian Sea ecoregion is an important area for aquaculture in Norway, and a total of 446, 20, 81, 37 sites are allocated for Atlantic salmon and rainbow trout, other fish species, molluscs, crustaceans and echinoderms, and algae, respectively (Table 2.1). The aquaculture activity in the ecoregion is mainly located along the coast, as shown in Figure 2.1. The main species farmed in this ecoregion (and in Norway) are Atlantic salmon and rainbow trout (ICES, 2020) farmed in open-net cages (Figure 2.2), and in each net, the total number of fish can be up to 200.000 individuals. The main part of the blue mussel (*Mytilus edulis*) production in Norway, is also located in this ecoregion (Figure 2.3). Further details on the aquaculture activities are given in the following sections.

**Table 2.1. Aquaculture sites by county in Norway (Norwegian Sea ecoregion counties are shown in bold). Source: Norwegian Directorate of Fisheries, 2021.**

| County | Atlantic salmon and rainbow trout | Other fish species | Molluscs, crustaceans and enchinoderms[1] | Algae |
|---|---|---|---|---|
| Troms and Finnmark | 196 | 6 | 3 | 3 |
| **Nordland** | **203** | **8** | **39** | **19** |
| **Trøndelag** | **163** | **9** | **40** | **10** |
| **Møre and Romsdal** | **80** | **3** | **2** | **8** |
| Vestland | 272 | 8 | 45 | 47 |
| Rogaland | 62 | 2 | 5 | 3 |
| Agder | 10 | 0 | 6 | 3 |
| Other counties | 0 | 0 | 1 | 0 |
| **Total** | **986** | **36** | **141** | **93** |

**[1] Molluscs, crustaceans and echinoderms includes blue mussels, scallops, oysters and other shellfish.**

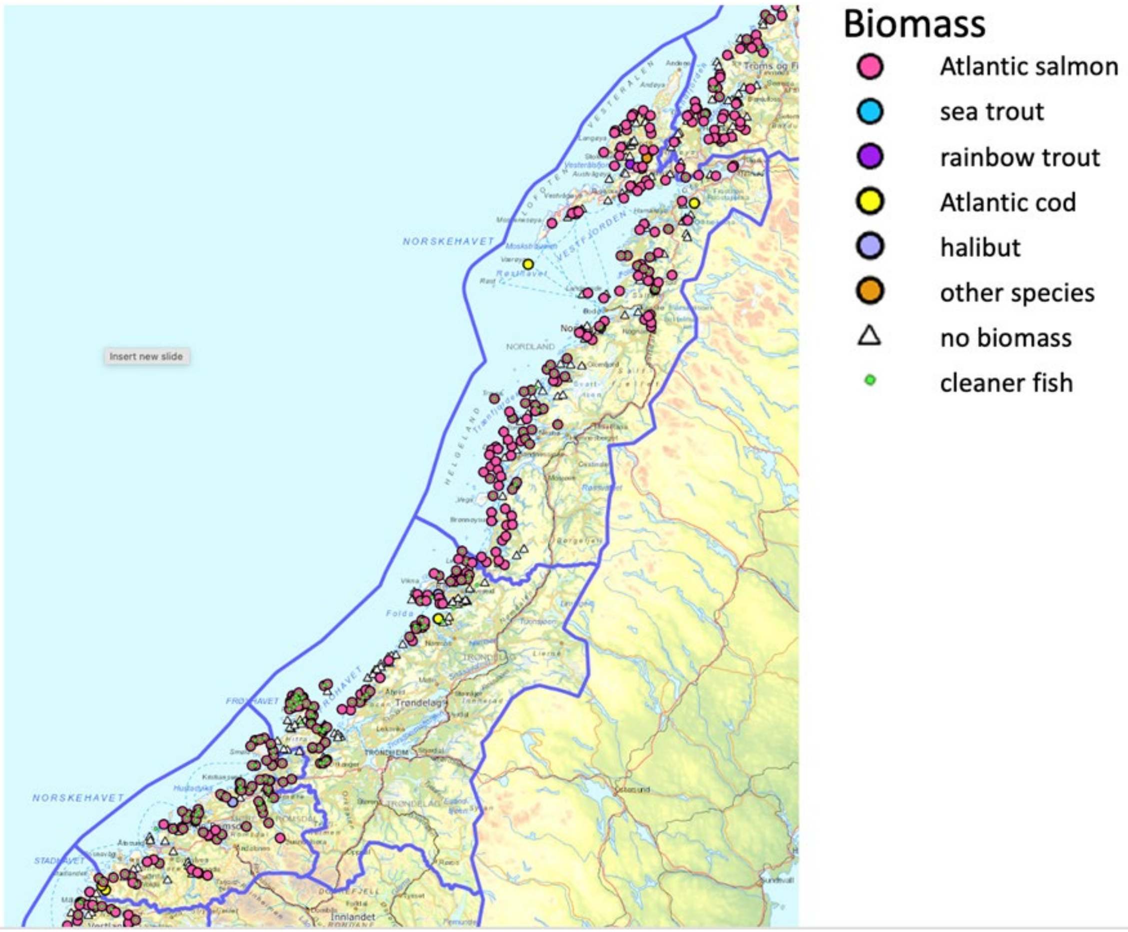

Figure 2.1. Aquaculture sites with biomass for different species June 2021. Blue lines show county borders (counties bordering the Norwegian Sea ecoregion from south to north: Møre and Romsdal, Trøndelag and Nordland). Source: Norwegian Directorate of Fisheries (https://portal.fiskeridir.no/portal/apps/webappviewer/index.html?id=87d862c458774397a8466b148e3dd147).

Figure 2.2. Farm for production of Atlantic salmon in the Lofoten area in Nordland County. Photo: Erwann Legrand, Institute of Marine Research-IMR.

Figure 2.3. Blue mussel farm in Åfjorden in Trøndelag County. Photo: Tore Strohmeier, Institute of Marine Research-IMR.

# 3 Production over time

Since the start around 1970, salmon aquaculture has become an important industry in Norway. There is also production of other species, but Atlantic salmon accounted for 94% of the volume in tonnes in 2019 (Table 3.1). The production of Atlantic salmon has been steadily rising since the mid-1980s but has flattened out at around 1.3–1.4 million tonnes since 2012 (Figure 3.1). The production of rainbow trout has remained stable at about 80 000 tonnes annually since the early 2000s. Other species in aquaculture production includes trout (*Salmo trutta*), Atlantic halibut (*Hippoglossus hippoglossus*), Atlantic cod (*Gadus morhua*), Arctic char (*Salvelinus alpinus*), as well as the invertebrates molluscs, crustaceans and echinoderms. However, the production of these species accounted for 0.23% of the total aquaculture production in Norway in 2019 (Table 3.1). For cod, all the production was based on wild-caught fish in 2019, but in 2018 all of it was based on hatched juveniles.

**Table 3.1. Aquaculture production in Norwegian Sea ecoregion (by county and total) and in total in Norway in 2019. Numbers are given in metric tonnes. Source: Norwegian Directorate of Fisheries, 2021.**

| | **Norwegian Sea ecoregion** | | | | **Norway** |
|---|---|---|---|---|---|
| Species | Nordland | Trøndelag | Møre og Romsdal | Total | |
| Atlantic salmon | 305 301 | 201 575 | 186 766 | 693 641 | 1 364 042 |
| Rainbow trout | 4395 | 2592 | 12 992 | 19 979 | 83 290 |
| Brown trout | 0 | 0 | 0 | 0 | 199 |
| Other fish species[1] | 1145 | 201 | 0 | 1346 | 3230 |
| Molluscs, crustaceans and echinoderms[2] | 839 | 1243 | 8 | 2090 | 2164 |
| Algae | | | | | 117 |
| **Total** | **311 680** | **205 611** | **199 766** | **717 056** | **1 453 042** |

[1] **'Other fish species' includes Atlantic cod, Arctic char, and minor quantities of other species.**

[2] **'Molluscs, crustaceans and echinoderms' includes blue mussels, scallops, oysters and other shellfish.**

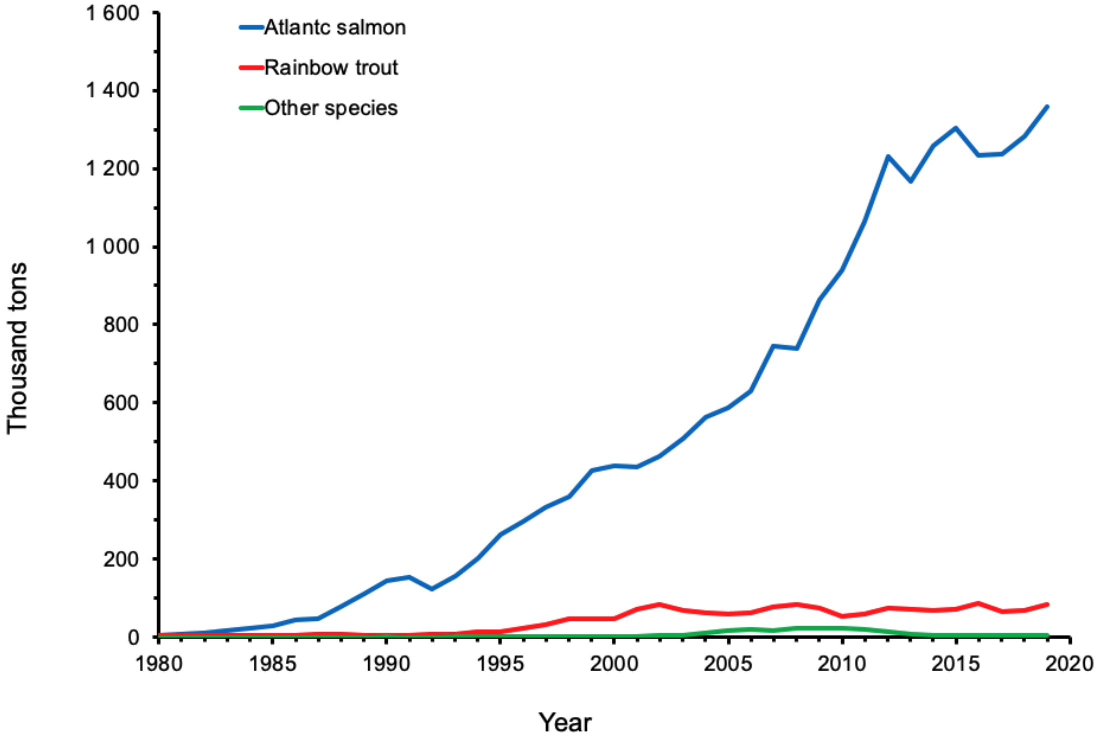

**Figure 3.1. Production of Atlantic salmon, rainbow trout and other species (see Table 3.1) in Norway from 1980–2019, in tonnes. Source: Norwegian Directorate of Fisheries, 2021.**

The aquaculture production in the Norwegian Sea ecoregion (counties of Møre og Romsdal, Trøndelag, and Nordland) constituted about 50% of the aquaculture production in Norway in 2019 (Table 3.1). The production of salmon in the ecoregion has increased continuously since 1998 (Figure 3.2a). However, since around 2010 this increase is mostly due to increased production in the northernmost county, Nordland. The production of rainbow trout has remained low and decreased since 2008 (Figure 3.2a). The production of other fish species reached a maximum in the period 2008–2011, primarily driven by a top in Atlantic cod production (Figure 3.2b). Finally, the production of echinoderms, molluscs and crustaceans are increasing in the ecoregion, yet at very low levels compared to Atlantic salmon (Figure 3.2c).

Aquaculture production also includes the production of juvenile fish, mainly of salmonids but the demand for cleaner fish has increased the production of ballan wrasse (*Labrus begylta*) and especially lumpfish (*Cyclopterus lumpus*) substantially since 2016. On a national basis, 372 million salmon juveniles were produced in 2019, constituting around 84% of all juveniles produced (Table 3.2). As with the increasing salmon production over the last decades, also the production of juveniles has steadily increased over the last decades in the ecoregion (Figure 3.3).

**Table 3.2. Juvenile fish production in Norway in 2019 (information not available by counties). Numbers are given in metric tonnes. Source: Norwegian Directorate of Fisheries, 2021.**

| Species | Numbers x 1000 | Proportion |
|---|---|---|
| Atlantic salmon | 372 492 | 0.840 |
| Rainbow trout | 28 155 | 0.064 |
| Trout | 0 | 0 |
| Cod | 460 | 0.001 |

| Species | Numbers x 1000 | Proportion |
|---|---|---|
| Arctic char | 1225 | 0.003 |
| Halibut | 1306 | 0.003 |
| Others | 31 | 0.000 |
| Wrasse | 681 | 0.002 |
| Lumpfish | 39 054 | 0.088 |

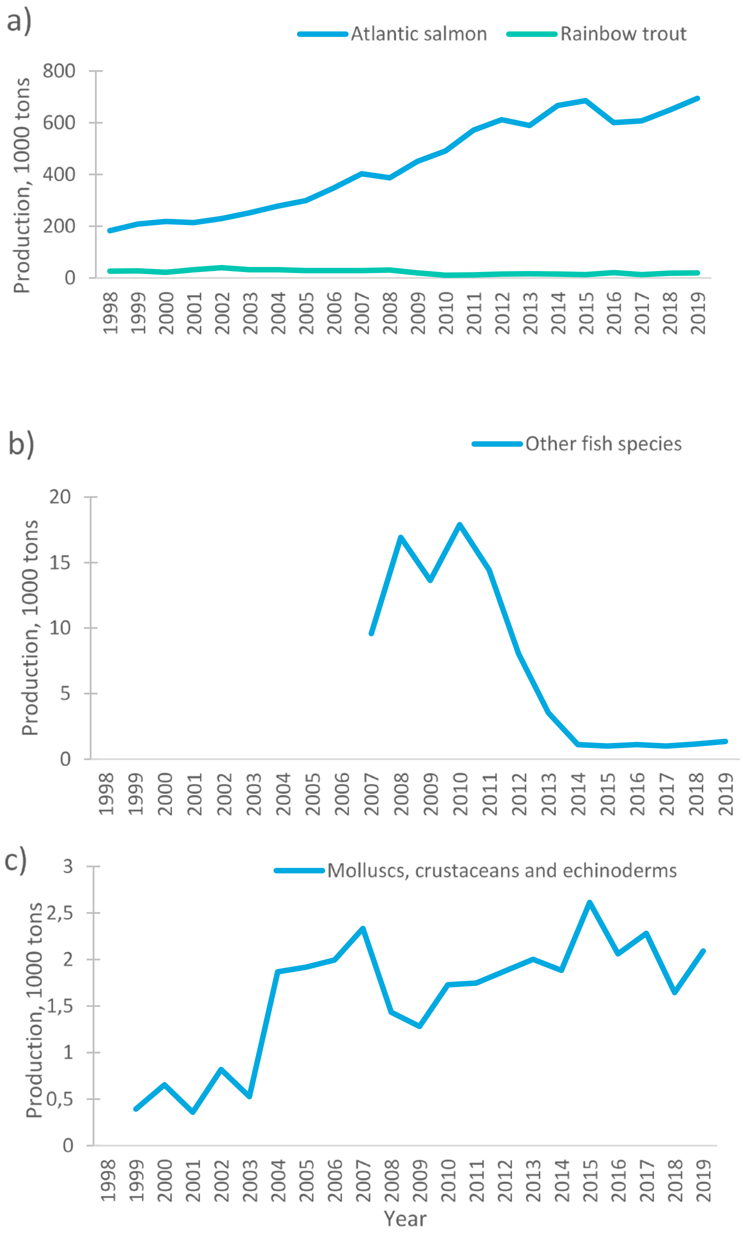

**Figure 3.2. Aquaculture production in the Norwegian Sea ecoregion (counties of Nordland, Trøndelag and Møre og Romsdal) of a) Atlantic salmon, Rainbow trout, b) other fish species and c) echinoderms, molluscs and crustaceans, in 1000 tonnes. Source: Norwegian Directorate of Fisheries, 2021.**

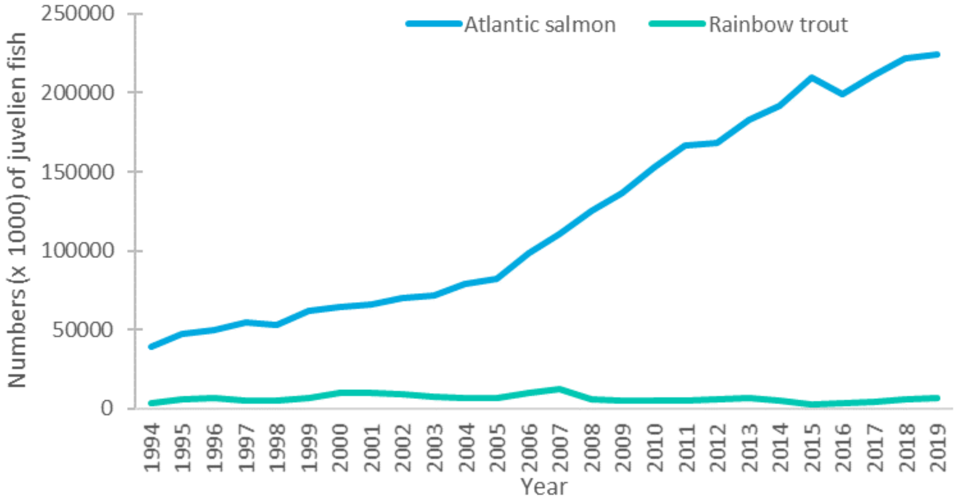

**Figure 3.3. Production of juvenile Atlantic salmon and rainbow trout (numbers x 1000) in the Norwegian Sea ecoregion (counties of Nordland, Trøndelag and Møre og Romsdal). Source: Norwegian Directorate of Fisheries, 2021.**

# 4 Policy and legal foundation

The central legislative document for aquaculture in Norway is the Aquaculture Act of 2005, and its formal regulations (Aquaculture Act, 2005). The Norwegian legislative system is based on Acts that typically gives general limitations and directions, and then gives the government ("The King", as it is stated in the Acts) or the relevant ministry the authority to make more specific rules through formal regulations. So also, for the Aquaculture Act. This means that for some concerns, the rules governing aquaculture can be adjusted relatively quickly, and without the need to involve the parliament, which is the institution issuing laws. As of April 2021, there are 25 formal regulations authorized in the Aquaculture Act. The objective of the Aquaculture Act is "to promote the profitability and competitiveness of the aquaculture industry within the framework of a sustainable development and contribute to the creation of value on the coast" (§1). For a historic development of aquaculture in Norway, see Annex 3

## 4.1 Licencing

Aquaculture production in Norway requires a license. A license gives the right to produce certain species within specified geographic areas (localities) under the limitations set by the license. Aquaculture production is defined as any measures to affect the weight, size, numbers, properties or qualities of aquatic organisms. Norwegian aquaculture is dominated by the farming of Atlantic salmon in terms of production, value and also number of licenses. The issuing of licenses for grow-out of Atlantic salmon, rainbow trout and sea trout in sea cages is regulated by a separate regulation (FOR-2004-12-22-1798), in addition to the Aquaculture Act itself. The regulation also covers special licenses for Atlantic salmon, sea trout and rainbow trout. These latter include juvenile production, broodstock and slaughter cages, and also for research, development, education, and viewing (ICES, 2020). Licenses for aquaculture of other species are covered by another regulation (FOR-2004-12-22-1799).

Licenses for commercial grow-out of Atlantic salmon, sea trout and rainbow trout in seawater are limited, and the ministry decides when new licenses are to be issued and their geographic allocation, and can also set other special requirements or criteria for allocation. Before 2017, new licenses were issued in rounds with many different types of requirements and criteria (Hersoug *et al.*, 2020). Since 2017, the commercial production capacity for grow-out of Atlantic salmon, sea trout and rainbow trout, and in consequence also new licenses for this, are regulated through a "traffic-light system" (Ministry of Trade, Industry and Fisheries, 2015, FOR-2017-01-16-61). More on that below. Other types of aquaculture licenses, both for salmon, sea trout and rainbow trout, and other species, are generally granted on an ongoing basis based on applications.

Table 4.1 gives an overview of the number of licenses for different groups of species in Norway at the end of 2020, by county. Licenses for Atlantic salmon, rainbow trout and sea trout dominate, and the number has grown steadily over the years (Norwegian Directorate of Fisheries, 2021). The number of licenses for other fish species has historically been higher. In 2007, it was over 750 (op cit.), but each license for other fish species can be for several individual species (Table 4.4). The fish species listed in Table 4.4 are all farmed for human consumption, except wrasse and lumpfish, which are used in salmon farming to limit salmon lice by grazing on them. Some of the licenses for other fish species are for aquaculture of wild-caught fish. The number of licenses for molluscs, crustaceans and echinoderms has also been much higher previously than in 2020. There were over 900 licenses in 2003–2004 (op cit.). The first licenses for algae production were granted in 2014, but algae licenses are already the second-largest group. Not all of the granted aquaculture licenses are in use at any one time, though (Table 4.2.). While almost all grow-out licenses for Atlantic salmon, sea trout and rainbow trout were in use in 2019, only half of the licenses for molluscs, crustaceans and echinoderms were in use, and around a third of the licenses for other fish species and for algae.

The Norwegian Sea ecoregion is an important area for aquaculture in Norway, with a large share of all the aquaculture licenses granted, for all types of aquaculture (Table 4.1 and 4.3).

**Table 4.1. Aquaculture licenses by county in Norway (counties bordering the Norwegian Sea ecoregion are shown in bold). Source: Norwegian Directorate of Fisheries, 2021.**

| County | Atlantic salmon, sea trout and rainbow trout[1] | Other fish species[2] | Molluscs, crustaceans and echinoderms[3] | Algae | Sea Ranching |
|---|---|---|---|---|---|
| Troms og Finnmark | 267 | 29 | 13 | 6 | 0 |
| **Nordland** | **293** | **41** | **41** | **173** | **0** |
| **Trøndelag** | **270** | **48** | **46** | **23** | **1** |
| **Møre og Romsdal** | **162** | **29** | **8** | **12** | **1** |
| Vestland | 381 | 85 | 72 | 280 | 0 |
| Rogaland | 104 | 26 | 18 | 3 | 3 |
| Agder | 27 | 14 | 12 | 14 | 2 |
| Other counties | 36 | 18 | 5 | 0 | 0 |
| **Total** | **1540** | **290** | **215** | **511** | **7** |
| **NSER[4] sum** | **725** | **118** | **95** | **208** | **2** |
| **NSER[4] share** | **47%** | **41%** | **44%** | **41%** | **29%** |

[1] **'Atlantic salmon, rainbow trout and trout' include commercial grow-out and juveniles, breed stock, education, research, development and viewing licenses.**

[2] **'Other fish species' includes grow out- and broodstock licenses.**

[3] **'Molluscs, crustaceans and echinoderms' include blue mussels, scallops, oysters and other shellfish.**

[4] **Norwegian Sea ecoregion.**

**Table 4.2. Share of licenses with production in 2019 in % (Source: Norwegian Directorate of Fisheries, 2021)**

| | Atlantic salmon, sea trout and rainbow trout | Other fish species | Molluscs, crustaceans and enchinoderms[1] | Algae |
|---|---|---|---|---|
| Grow-out | 98 | 30 | 53 | 35 |
| Juveniles | 82 | | | |

[1] **'Molluscs, crustaceans and echinoderms' includes blue mussels, scallops, oysters and other shellfish.**

**Table 4.3. Aquaculture licenses for Atlantic salmon, sea trout and rainbow trout by county in Norway and type of license (counties bordering the Norwegian Sea ecoregion are shown in bold). Source: Norwegian Directorate of Fisheries, 2021.**

| County | Grow out | Broodstock | Juveniles | Research | Viewing | Development |
|---|---|---|---|---|---|---|
| Troms and Finnmark | 215 | 2 | 21 | 16 | 5 | 8 |
| **Nordland** | **197** | **10** | **33** | **25** | **9** | **19** |
| **Trøndelag** | **189** | **10** | **37** | **21** | **4** | **9** |
| **Møre and Romsdal** | **113** | **5** | **33** | **10** | **1** | **0** |
| Vestland | 260 | 10 | 76 | 28 | 7 | 0 |
| Rogaland | 64 | 5 | 18 | 16 | 1 | 0 |
| Agder | 22 | 1 | 4 | 0 | 0 | 0 |
| Other counties | 27 | 2 | 5 | 2 | 0 | 0 |
| **Total** | **1087** | **45** | **227** | **118** | **27** | **36** |

**Table 4.4. Aquaculture licenses in Norway for other fish species than Atlantic salmon, sea trout, and rainbow trout, by species. Source: Directorate of Fisheries, 2021.**

| Species | No. of licenses¹⁾ |
|---|---|
| Atlantic haddock | 20 |
| Atlantic halibut | 64 |
| Wrasse | 182 |
| European hake | 11 |
| Turbot | 31 |
| Lumpfish | 80 |
| Arctic char | 53 |
| Wolfish | 53 |
| Cod | 85 |
| European eel | 15 |
| Other species | 390 |
| **Total** | **984** |

**1) Some licences comprehend several species. In the table above some licences are counted several times. The total number of licences in the table above are therefore higher than the total number presented in the table specified on counties.**

Formally, an aquaculture license consists of two parts, the "general license" to farm a specific species in a specific volume, and the "site license" to do so at one or several specific locations. For Atlantic salmon, sea trout and rainbow trout, each general license is typically associated with several site licenses, and a site license may be associated with several general licenses. This explains why the number of approved sites in seawater for grow-out of Atlantic salmon, sea trout and rainbow trout can differ from the number of general licenses for these species, as Table 2.1 shows. After the fish at a site has been slaughtered, the site is fallowed for a period to let the bottom sediment and local environment recover. The general license can however be utilized on another site while the first site is fallowed.

For farming of fish, both the general license and the site license has been specified in *maximum allowable biomass* (MAB), corresponding to the highest biomass of fish that can be kept at any given time. The typical MAB size for a general license has been 780 tonnes. For aquaculture licenses for Atlantic salmon, sea trout and rainbow trout in the northernmost county of Troms and Finnmark, the MAB limit has been 945 tonnes. After the introduction of the traffic light system (see below), the standard MAB license sizes of 780 and 945 tonnes are no longer relevant to salmonids, but they are still valid for other fish species. There is no standard MAB size for site licenses, and they vary considerably. In 2017, the average MAB size for site licenses in the Norwegian counties varied from 2711 to 4250 tonnes, with an average of 3446 tonnes (Hersoug *et al.,* 2021). Licenses for farming mussels and plants (algae) are specified in the area (da), but there is no standard license size.

To get a site license, the aquaculture site must be cleared for use. Applications for site licenses for Atlantic salmon, sea trout and rainbow trout, as well as general licenses for other species, are submitted to the county council where it is to be located. They coordinate the process and make the formal decision. An aquaculture license may only be granted if it is (Aquaculture Act 2005; §6) environmentally responsible, not in conflict with conservation measures or land use plans, land use interests have been weighed, and necessary permits are granted from the County Governor, the Food Safety Authority, the Coastal Administration and the Water Directorate. Authorities also provide a hearing. In total, the governance of aquaculture sites involves a large number of ministries, state directorates with both central and regional offices, and regional and local political authorities, with mandates from seven different legal acts (Hersoug *et al.,* 2021). There is also a mandatory public hearing process before the county council make their decision.

## 4.2 Aquaculture at sea

Aquaculture in the sea is currently only taking place in the coastal zone (defined as the area inside of 1 nm beyond the baseline). A fish farm must be in a defined aquaculture zone in the relevant land-use plan, which normally is a municipal coastal-zone plan after the Planning and Building Act (2008). Alternatively, the fish farm can be placed with an exemption from the land use plan by the municipal council. The Planning and Building Act opens up for state-mandated area plans, but these are very rare for aquaculture. Several authorities besides the municipalities play key roles in making municipal land use plans, through the possibility to formally object to a proposed plan. If the formal objection is not resolved through negotiations between the municipality and the other authority, the Ministry responsible for the Planning and Building Act will decide on the matter. A public hearing is mandatory when municipal land-use plans are made, first before the planning process is decided, and then before the final plan is decided. In summary, authorities both at the local, regional and national levels are central in allowing aquaculture and facilitating the growth of it, and public hearings are also mandatory.

The policy and legal regime for aquaculture in Norway vary somewhat with where aquaculture takes place. The Aquaculture Act is valid for all parts of the Norwegian territory. The PZ regulation, which is fundamental for the traffic light system, has jurisdiction out to 30 nm from the coast. Area-planning for the coastal zone (out to 1 nm beyond the baseline) is regulated based on the Planning and Building Act, and with the municipal councils responsible for the planning. Currently, there is no separate legal regime for area planning for aquaculture outside the coastal zone, but Norway has made Integrated Management Plans for the major ocean areas, which gives policy for area issues, including for the Norwegian Sea (Ministry of Trade, Industry and Fisheries, 2020).

There are initiatives to develop and implement aquaculture off the coastal zone (offshore aquaculture), both through technology development and for policy and legislation. An inter-ministerial working group has considered various issues related to risks and regulation of offshore aquaculture (Ministry of Trade, Industry and Fisheries, 2018), and the Ministry of Trade, Industry and Fisheries are currently (April 2021) working on a new aquaculture strategy where offshore aquaculture is expected to be covered.

Technology development or implementation, especially to deal with environmental, area or fish health challenges, have been encouraged through several licensing rounds (Hersoug *et al.*, 2019), including the "green round" announced in 2013. Radical technology development is currently supported by *development licenses*. From November 2015 to November 2017, the ministry opened up for applications for development licenses in the salmon allocation regulation (FOR-2004-12-22-1798; §23b). Such licenses could be given to projects that contribute to developing technology that can help solve one or more of the environmental and area-related challenges in aquaculture, and which include significant innovation and significant investments. In total, 104 applications were received (Norwegian Directorate of Fisheries, 2021b). They included a range of technologies involving land-based to offshore farming, open and closed farms, and some technologies more independent of type of farm. As of April 2021, 21 projects are approved, 80 are rejected and 3 are still being considered. The applications ranged from asking for one to 45 "standard" licenses of 780 tonnes MAB. The actual number of standards licenses granted have in many cases differ from what was applied for. The biggest approved project has got 21 standard licenses. After successful completion of the project behind a development license, the license can be converted to an ordinary license for a fee of 10 million NOK per standard license (inflation-adjusted from 2017). This implies a considerable subsidy compared to the fees paid for new production capacity in the latter years under the traffic light regime (Mikkelsen, 2019). It is not a requirement for conversion that the development project have succeeded in developing new technology nor that it will be used. The requirement is that the development project's goals have been met. It has been a requirement that knowledge from the development projects must be shared, and the Directorate of Fisheries has set up a web page with this information (Norwegian Directorate of Fisheries, 2021c).

## 4.3 Traffic light system

The traffic light system was introduced in 2017 for the adjustment of production capacity for Atlantic salmon, sea trout and rainbow trout aquaculture. The objective was to achieve a more predictable system for growth in aquaculture production while taking environmental sustainability into account (Ministry of Trade, Industry and Fisheries, 2015). In this system, the coast of Norway is divided into 13 PZs, and within each zone, the impact of salmon lice originating in fish farms on populations of wild salmon is regularly assessed by an expert committee. They assess whether the lice-induced mortality in each PZ is within one of three predefined categories: less than 10% ("green zone"), between 10–30% ("yellow"), or above 30% ("red"). They also consider the level of certainty/uncertainty in their assessments. Based on the expert committee's report and advice from a steering group, the ministry decides on the colouring of the PZs for the regulation of production capacity for the next two years. In green PZs, the capacity can increase by 6%, in red zones, it must be reduced by 6%, while in yellow areas it remains constant. In 2018 and 2020, the farmers already operating within a green zone were offered to buy some increased production capacity at a fixed price per ton maximum allowed biomass, and the remaining increase in production capacity up to 6% was open for anyone that fulfilled some minimum qualification requirements to bid on. Farms that fulfilled certain "exemption criteria" related to salmon lice numbers and treatments against salmon lice could buy a 6% production capacity increase, regardless of the colour set for the PZ they were in. The production capacity increase from these exemptions was also deducted before the auctions of production capacity increases for the PZs. The aim of the traffic light system is to be a regime for predictable and environmentally sustainable growth, where the mechanism for allocation of production capacity is objective rather than discretionary (Ministry of Trade, Industry and Fisheries, 2015). Based on the environmental sustainability situation, potential production capacity adjustments are decided every second year, and the allocation of actual changes in production capacity between farmers depend on their willingness to pay. However, the traffic light system currently only considers the impact of salmon lice originating in the farms on wild salmon populations. Environmental sustainability of aquaculture concerns several other impacts, as is described in Section 5, and illustrated in Figure 4.1.

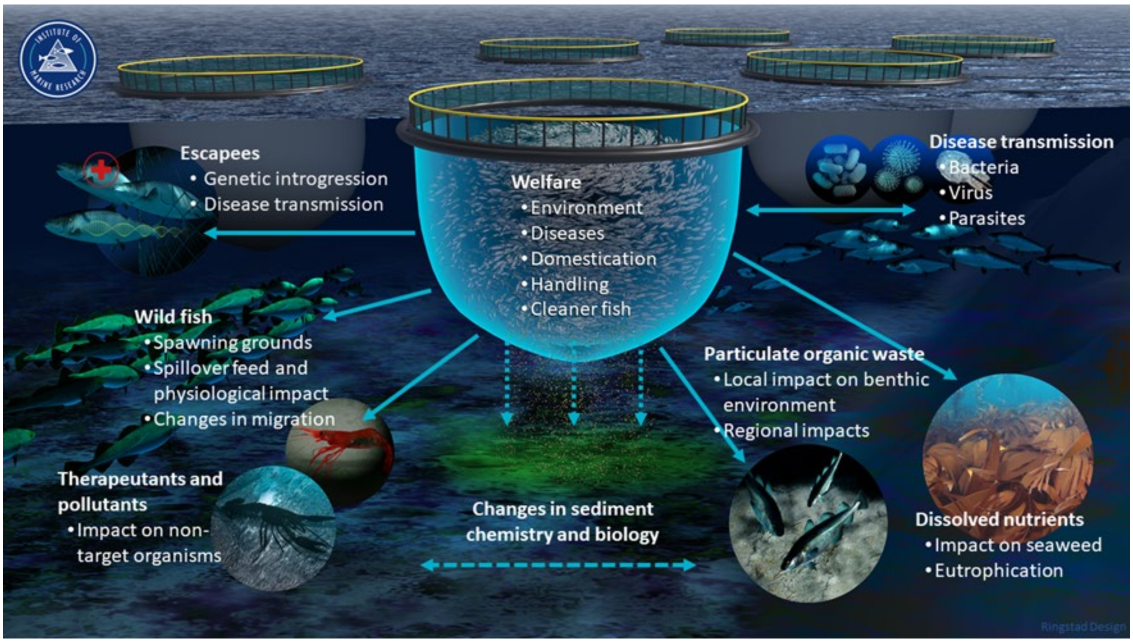

**Figure 4.1. Environmental impacts of fish farming in open-net pens and identified risk factors. Illustration: Institute of Marine Research-IMR.**

## 4.4 Enabling sustainability

Enabling and ensuring environmentally sustainable aquaculture relates to legislation and governance regarding setting aside areas for aquaculture in area plans, the issuing of licenses and clearance of sites, the monitoring, control and sanctioning of aquaculture operations, and also creating incentives for the development of new technology and practices. Important risk factors for environmental sustainability have been identified and described (e.g. Ministry of Trade, Industry and Fisheries, 2015, Grefsrud *et al.*, 2021ab), and indicators, threshold values and rules of action have been, or are in the process to be implemented, for impacts of salmon lice from farming on wild populations in the PZs (FOR-2017-01-16-61), escapes and genetic impacts in salmon rivers (FOR-2013-09-20-1109), regulations on joint responsibility for removing of escaped farmed fish (FOR-2015-02-05-89), and emissions and organic impact at the production site and surrounding areas (FOR-2006-12-15-1446; Norsk Standard, 2016). For the other identified risk factors, more knowledge is needed on the extent and severity before the authorities have sufficient knowledge to determine the level of protection with associated indicators and threshold level. In cases with little empirical knowledge, it is important to define and highlight the level of uncertainty, and in such cases, an expert assessment based on the best available knowledge will often be required (Grefsrud *et al.*, 2021a).

The Norwegian legislation includes measures for the prevention of pathogens being introduced or spread, e.g. by import or transmission between farms. This regards both the health and welfare of the farmed fish as well as risks and impacts on wild fish populations. The farmers must monitor and report from salmon lice counting and if they suspect or detect disease, and also regularly have independent assessments of bottom conditions under the farms. National surveillance programs and mandatory, frequent fish health controls contribute to detecting diseases. If pathogens are introduced and create problems in farms or areas, the legislation, inspections, samplings and contingency plans facilitate adequate countermeasures. Among the measures, the authorities can order are reductions in biomass and total out-slaughtering from a site.

Economic and social sustainability have been important concerns in the Norwegian aquaculture legislation since the first (temporary) Aquaculture Act of 1973 (Hersoug *et al.*, 2019), although the term sustainability was not formally introduced before 1991 (Mikkelsen *et al.*, 2018). The distribution of benefits from aquaculture activities has been a major issue, including through regulating ownership and stimulating local and regional industrial development and other rural policy objectives. Developments in technology and operations and industrial and ownership structure have led to a more skewed regional distribution of benefits of employment and income, and also income to the municipal councils of the areas where salmon farms are located (Tiller *et al.*, 2012). A municipal area fee for salmon farming has been proposed by various actors over the years, from the beginning of the 2000s, but has never been decided. From 2009, the municipalities were allowed to levy a property tax on aquaculture installations (Hersoug *et al.*, 2021)

As the profitability of salmon farming in Norway increased considerably (Johansen *et al.*, 2019; Iversen *et al.*, 2020), the political pressure grew to do something with the skewed distribution of benefits. The use of auctions to allocate new licenses for the 2013-announced "green round" also made the value of an aquaculture license more visible (Hersoug *et al.*, 2019). Before this auction, the most expensive licenses had had a fixed price of 10 million NOK for 780 tonnes MAB, but then they sold for 55 million NOK. With the introduction of the traffic light system auctioning of new capacity was introduced as the main allocation mechanism, implying that there could be considerable total fees coming in.

## 4.5 Norwegian Aquaculture Fund

Norwegian Aquaculture Fund was established in 2016. The fees from allocation of new production capacity 2016–2018 were shared between the state (20%) and the Aquaculture Fund (80%) (Norwegian Directorate of Fisheries, 2021d). The funds in the Aquaculture Fund are in turn shared between the municipalities (7/8) and counties (1/7) that have salmon farming sites. The allocation is further mainly decided by the municipalities and counties' relative share of the total site MAB capacity, but with some extra funds to those that have cleared new sites the last two years. All of the funds coming in are paid out within two years, not just the returns on the funds.

Despite 80% of fees from new production capacity sales being channelled into the Aquaculture Fund, the criticism continued. The parliament decided in 2017 to ask the government to establish an export fee on farmed salmon, and that also these fees should go into the Aquaculture Fund for distribution to the municipalities and counties. This was rejected by the government, but they established an expert commission to consider how the tax system for aquaculture should be to ensure that a share of the ground rent in aquaculture goes to the greater public, how the division should be between the state and the municipalities, and how the municipalities' share of the income could become more stable and predictable (NOU, 2019). The committee's suggestions were not implemented, but a new system was decided. From 2021, a municipal production fee of 0.40 NOK per kg slaughtered farmed salmon and trout is established, payable from 2022. The allocation of fees paid for new production capacity for salmon and trout will be changed so that the state gets 60% and 40% goes into the Aquaculture Fund. For 2020 and 2021, specific state transfers into the Aquaculture Fund were decided, independent of the actual fees paid by the farmers.

It is only sea-based farms of Atlantic salmon, sea trout and rainbow trout out to 12 nm that must pay fees for new production capacity or licenses. Land-based farms are exempt from such fees. Offshore farms beyond 12 nm are similarly exempt, at least currently.

# 5 Ecosystem/environment interactions

## 5.1 Introduction

Environmental impacts are one of the limitations for further aquaculture growth and the tools needed for sustainable development and management rely on a better understanding of how aquaculture activities interact with the environment. In the Norwegian Sea ecoregion, the aquaculture production consists mostly of salmonids and the main focus of this section will be on environmental interactions of salmon (*Salmo salar*) and rainbow trout (*Onchorhynchus mykiss*) farming.

Since 2011, the Institute of Marine Research (IMR) has conducted yearly risk assessments on many of the environmental hazards caused by salmonid farming (Taranger *et al.,* 2015). The main focus has been on the effects of sea lice, pathogens, escaped farmed salmon, effluents, use of wild-caught wrasse for de-lousing and animal welfare. In addition to these topics, this section gives a short summary of interactions with sea mammals and seabirds and also includes some information on aquaculture production of seaweed, blue mussels (*Mytilus edulis*), and Atlantic cod (*Gadus morhua*) in the Norwegian Sea ecoregion.

The following paragraphs give a short summary of the status of environmental impacts from aquaculture. More details about the environmental hazards of salmonid farming with references can be found in Annex 4.

## 5.2 Environmental interactions of aquaculture

### 5.2.1 Salmonid farming

The salmon louse *Lepeophtheirus salmonis* is the most abundant parasite that affects farmed Atlantic salmon and is, according to the Norwegian Scientific Advisory Committee for Atlantic Salmon, considered the major threat to wild salmon (VRL, 2020). Today, the estimated lice-induced additional mortality of wild salmonids limits the capacity growth in salmon aquaculture through predefined categories (traffic light system). In the Norwegian Sea ecoregion risk associated with mortality in migrating post-smolt salmon as a result of emissions of salmon lice from fish farming is considered low in PZs 8 and 9 due to low emissions of sea lice during smolt migration. In PZs 6 and 7 the risk is considered moderate and in PZ 5 high. The increased risk level is mainly due to higher emissions of sea lice and an increased overlap in time and space between migrating smolt and lice. For grazing sea trout and Arctic char, the risk picture differs from that of salmon. In PZs 8 and 9, the risk of negative effects from salmon lice is considered moderate, while in PZs 5–7 (only sea trout) the risk is considered to be high, mainly due to a great overlap in time and space between sea trout and lice during the fish grazing period (Serra-Linares *et al.,* 2020; 2018). The main knowledge gaps identified is the lack of data on tolerance limits of sea lice infestations on salmonids in the wild, on migrating routes of salmon smolt, especially in PZs 5–7 and on the behaviour mechanisms of early return migration in sea trout and Arctic char.

In addition to sea lice, genetic introgression by escaped farmed salmon and disease transmissions from salmon farms are considered as main threats to wild salmon. The occurrence of viral diseases in wild salmon populations has been monitored by IMR since 2012 and although infected farmed fish have been found in salmon rivers, so far, no major outbreaks in wild salmon populations have been proven. Still, the number of infected farmed fish is high throughout the year in many areas, including PZs 5 and 6. Infections and outbreaks of infectious salmon anemia (ISA) and pancreas disease (PD) has to be notified to the authorities, but several diseases are not notified, making it difficult to assess the total infection pressure from aquaculture. Due to the complex interaction between pathogen, host and environment, knowledge of the underlying mechanisms and how they affect transmission and infection in wild salmonids is scarce. Development of model tools that can simulate the emission, spread and dilution in time and space of pathogens from farmed fish will be essential to close some of the knowledge gaps. In the Norwegian Sea ecoregion more than 300 000 farmed salmonids escaped during the period 2015–2019, more than half of these, about 172 000, escaped in PZ 7 (Grefsrud *et al.*, 2021). Until recently, weak constructions and/or poor maintenance of net pens combined with bad weather was the main cause of fish escapes. New analysis made by the Norwegian Directorate of Fisheries shows that today, handling operations like de-lousing or moving fish causes most escape events. Since 2015 removal of escaped fish has been implemented and is organized by the aquaculture industry association for removing escaped farmed fish (OURO). In the period 2016–2019, OURO removed a total of 758 escaped farmed salmon from rivers in PZs 5–9 (Grefsrud *et al.,* 2021). It is still too early to consider the effect on genetic introgression of this measure. The main knowledge gaps identified are the lack of reliable escape data, reliable data on number of escaped farmed salmon at the spawning grounds in the rivers and how robust the different salmon populations are to genetic introgression.

Emissions of dissolved nutrients and particulate organic matter (faeces and spillover feed) are released directly to the environment from the open net pens. As the coastal waters in the Norwegian Sea ecoregion are categorized as oligotrophic (nutrient-deficient) and fish farms are mainly located in moderate- to high wave-exposed areas with high currents that spread and dissolve the nutrients quickly. Thus, emissions of dissolved nutrients in this area are not considered to be an environmental challenge with today’s production level. Although the risk is considered low, the knowledge base is considered moderate to poor due to the lack of coastal water monitoring in this ecoregion. If the fish farm industry increases substantially in future, implementation of a monitoring program should be considered. impact of particulate organic matter on the benthic environment is monitored through Norsk Standard NS9410 and is considered to be within acceptable environmental limits for more than 95% of the active aquaculture farms (Grefsrud *et al.,* 2021). The standard is developed for soft bottom sediments and there are some concerns about the environmental impact on hard bottom communities. The knowledge gap is mainly on how hard bottom species are affected by particulate waste, especially the sedentary species that cannot move out of the high impact zone close to the farm. Several research projects have been conducted to close the knowledge gap and a new standard including methodology for monitoring hard bottom areas is under development.

A first evaluation of the impact of copper from aquaculture showed that 11–21% of the fish farms in PZ 5–8 have copper levels above the threshold limit (84 mg/kg dry weight) and these PZs are evaluated to have a moderate risk of negative impact of copper, while in PZ 9 2% of the fish farms have copper levels above the threshold limit and the risk of environmental impact is considered low (Grefsrud *et al.,* 2021). As copper accumulates over time, the local impact may be expected in future, especially in PZs 6 and 7 where the emissions are considered to be high. A monitoring program has been initiated by IMR in parts of Vestland County (Greater North Sea ecoregion) but should be considered implemented also in other areas, especially in high impact areas and areas with new farms to increase the knowledge of sedimentation patterns and accumulation rate over time. Better models on spreading and dilution of copper are needed to better understand how and where copper accumulate. More studies on the concentration of copper in the water column and how this affects pelagic organisms, especially early life stages, is also needed.

There is no detailed information on the use of anti-sea lice drugs in the Norwegian Sea ecoregion. In general, the impact is considered to be local and based on the IMR risk assessment the Norwegian Directorate of Fisheries has implemented regulations of emissions of bath treatment drugs near known shrimp grounds. No regulations are yet given for the use of in-feed drugs. More knowledge of sensitivity in non-target organisms and better model tools for dispersal and dilution is essential to calculate the impact of anti-sea lice drugs.

Based on current practice, the use of cleaner fish is not considered sustainable mainly due to welfare problems causing high mortality rates. Also, moving species over long distances to be released in open-net pens is not considered good practice due to the possibility of transmission of pathogens and of genetic introgression of escapees. PZ 8 is the northern limit for distribution of wrasse in Norway, thus most wrasse used for de-lousing have been transported over a long distance. In PZ 6, genetic studies of goldsinny wrasse and corkwing wrasse showed indications of introgression of imported fish in local populations (Faust *et al.,* 2021; 2018; Jansson *et al.,* 2017). Still, the use of cleaner fish for de-lousing is common in the salmon industry and is considered as a low impact method both from an environmental perspective and for the farmed fish. Measures have been made to ensure that the cleaner fish have proper hiding and resting places in the net pens, but mortality rates are still high. More knowledge is needed about how extensive the escape of cleaner fish is and also on how the high fishing pressure in some areas impact local wrasse populations. The use of farmed lumpfish for delousing has increased from zero to 39 million in 2019, but the knowledge of how the use of this species impacts the environment is lacking.

Based on mortality rates, the welfare situation for farmed salmon is considered to be bad in PZ 5 and moderate in PZs 6–9 (Grefsrud *et al.,* 2021). Indicators of poor welfare are disease, parasites, wounds and injuries, poor growth and weight loss, and deviant behaviour (Noble *et al.,* 2018). As mortality can be a consequence of poor animal welfare, it is regarded as an important indicator to determine the condition and status of the fish farming industry. The limits for what is considered acceptable mortality rates are not set but work is ongoing to develop mortality as an indicator to be used in the Traffic light system. The ministry aims to include more indicators in the years to come to get a more holistic approach to the impact of the aquaculture industry. One of the main challenges will be to weigh the various factors against each other and to set limits for acceptable and non-acceptable impacts.

### 5.2.2 Sea mammals

It does not seem that conflicts between marine mammals and aquaculture is a major problem in the ecoregion. However, there have been a couple of episodes where minke whales (*Balaenoptera acutorostrata*) and humpback whales (*Megaptera novaeangliae*) have become entangled in the anchors of the farms (Arne Bjørge, personal communication). What is probably more common is that coastal seals (harbour seals *Phoca vitulina*, and otters *Lutra lutra*) graze near fish farms with the possibility of increased stress levels in farmed fish. Studies of this kind of impact have not yet been conducted in Norway. The worst-case scenario of aquaculture-seal interactions is damage to fish pens with the subsequent mass escape of farmed fish. Until 2020, it was allowed to shoot seals at fish farms. Such killings were to be reported to the Norwegian Directorate of Fisheries, but very few if any killings have been reported. Entanglement of marine mammals, acoustic impact from Acoustic Deterrent Devices and vessel-based disturbance and collisions were discussed in Working Group on Marine Mammal Ecology (WGMME; ICES, 2021). So far, none of these issues seems to be a big problem in the Norwegian Sea ecoregion.

### 5.2.3 Seabirds

Environmental impacts of aquaculture activities on seabirds may include entanglement by the farm itself or by marine debris from the production, physiological impact through seabirds foraging on fish feed or switching from other food sources to the species cultured (e.g. mussels, oysters) and disturbance from the farm activity (noise, collision with farm or vessels, lighting) are also identified as possible hazards to seabird populations (Surman and Dunlop, 2015). Mitigation efforts such as covering the net pens with bird mesh, reducing the use of lighting, video monitoring (both above and below the water surface) to detect entangled birds, return of waste to the mainland for further deposition and reducing the speed of operating vessels may reduce the impact on seabirds. No risk assessment on the environmental impact of aquaculture on seabirds has been conducted in the Norwegian Sea ecoregion.

### 5.2.4 Seaweed and blue mussel farming

There are some locations producing macroalgae (PZs 5, 6, 8 and 9) and in PZs 6–8 there is longline production of blue mussels in a few areas. Seaweed cultivation is considered to have less negative environmental impacts compared to finfish farming while longline mussel production may have an impact on benthic communities, local hydrodynamics, phytoplankton abundance, zooplankton abundance, pathogen transmission and sensitive habitats (Visch, 2015; McKinnon *et al.*, 2003). No risk assessments have been conducted on seaweed or mussel production in this ecoregion.

# 6 Social and economic context

The Norwegian Aquaculture Act (2005) has both environmental, economic and social objectives: "The purpose of this Act is to promote the profitability and competitiveness of the aquaculture industry within the framework of a sustainable development and contribute to the creation of value on the coast" (Aquaculture Act 2005; §1).

## 6.1 Profitability

The concern for the profitability of salmon and trout farming has historically motivated limitations on new licenses or on actual production out of concern for i.e. the supply of juveniles, the total market demand for the products, and fear of import tariffs to major international markets, like the EU (Hersoug *et al.*, 2019). The profitability of the industry has also varied a lot. In the early years, there were low profitability and bankruptcy occurred due to disease outbreaks, and around 1990 due to overproduction compared to the market demand (Hersoug *et al.*, 2019). In the latter years, the average earnings per kg of fish produced have been high in Norway (Figure 6.2) and profitability measured as the operating margin has been very high (Figure 6.3). This can be explained, at least in part, by a limited number of new licenses being issued out of environmental concerns, particularly related to salmon lice, while demand internationally has grown. This is despite marked higher costs for feed and "other costs" (Figure 6.1). The latter increase is especially related to combatting salmon lice and diseases (Iversen *et al.*, 2019). Still, a comparison of the costs of producing farmed salmon among the major producer countries shows that Norway has had the lowest or second-lowest average production cost from 2002 to 2018, justifying Norway's position as the largest producer (Iversen *et al.*, 2020).

The profitability of the companies that operate only in the individual counties within the Norwegian Sea ecoregion show the same general development over time as the national average, but with some exemptions (Figure 6.2 and 6.3). Note that the figures are based on companies that operate *only* within each of these counties, and do not have operations in other counties. Most aquaculture companies in Norway have operations in several counties. The Nordland county salmon and trout farming companies have higher profitability than the national average all years 2008–2019, but the Møre og Romsdal county companies have poorer profitability than the national average nearly all those years. The profitability of the Trøndelag county companies is around the national average, but some years higher and some years lower.

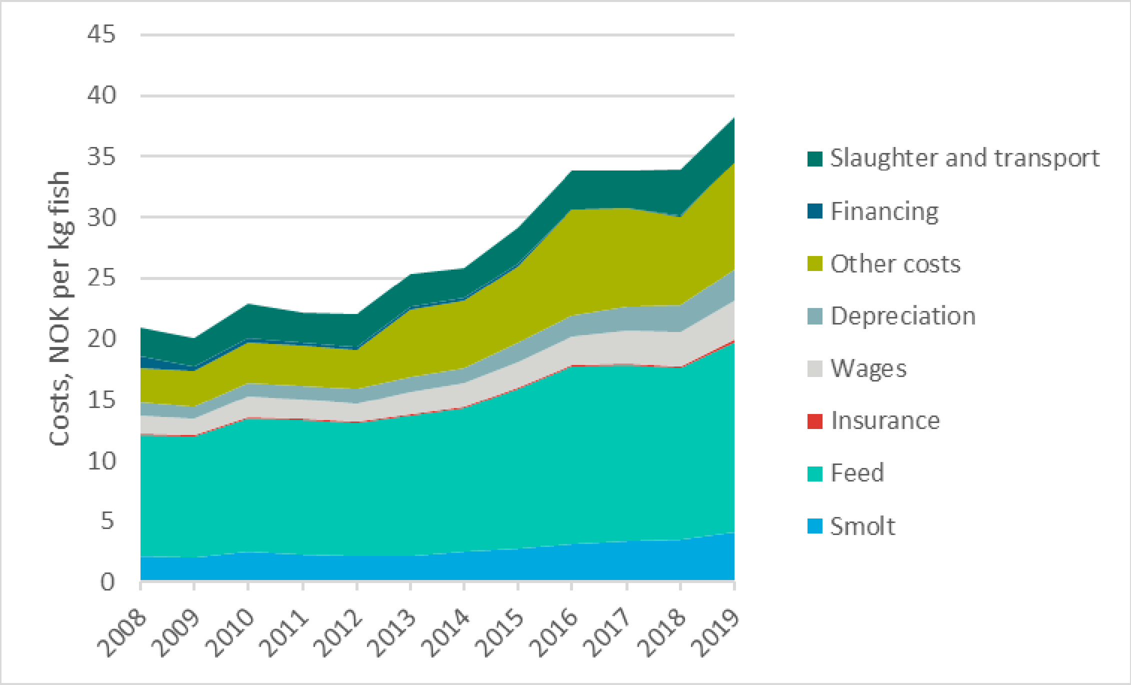

Figure 6.1. Costs per kg fish produced (salmon and trout), average for Norway. Nominal NOK. Source: Norwegian Directorate of Fisheries, 2021e.

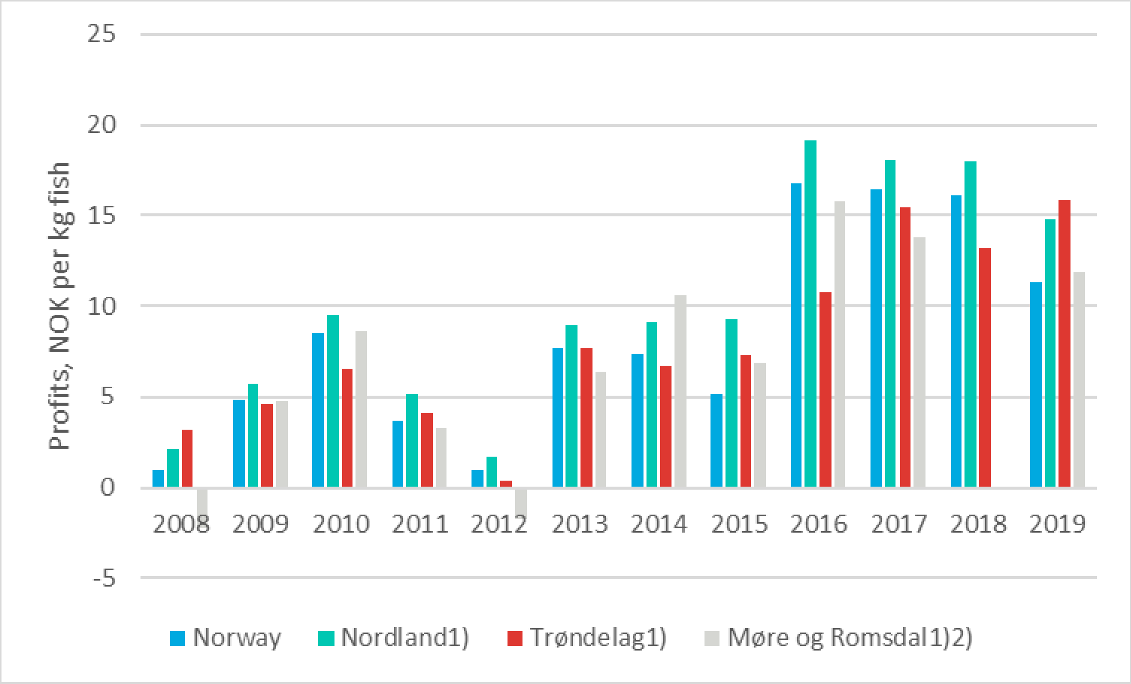

Figure 6.2. Profits per kg fish produced in salmon and trout farming. Nominal NOK. Source: Norwegian Directorate of Fisheries, 2021e. 1) For companies operating only in this county. 2) Information for 2018 not available.

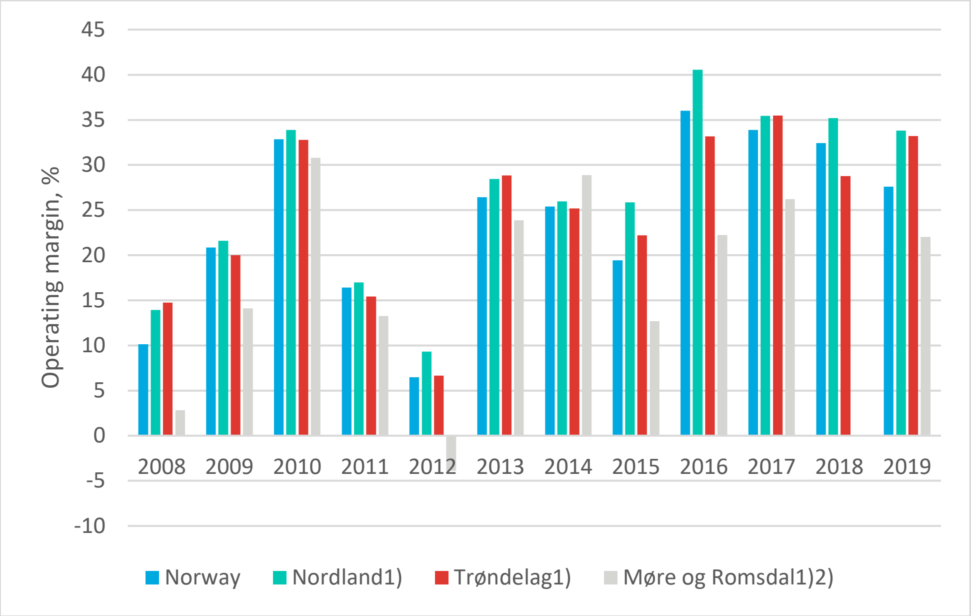

**Figure 6.3. Operating margin for farming of salmon and trout (%). Source: Norwegian Directorate of Fisheries, 2021.1) For companies operating only in this county. 2) Information for 2018 not available.**

## 6.2 Human population development and employment

An important social impact of industries is the jobs and employment they give, and through that give a foundation for settlement and population. Like most countries, Norway has experienced centralization of higher human population growth in urban areas than in rural areas (NOU 2020b; 31). Except for a few larger cities, the coastal areas are made up of rural municipalities (op cit.; 28). These patterns are also evident when the population development is considered for the counties that make up the Norwegian Sea ecoregion (Figure 6.1). Trøndelag county, with Norway's third-largest city Trondheim, has had a development only slighter weaker than Norway as a whole. County of Møre og Romsdal, and especially Nordland, have had a much weaker development. Norland's county population in 2021 is actually no bigger than it was in 1970, while Norway's total population over the same period has increased by 40%.

The employment-related to aquaculture has increased over time, as production has increased. For 2019, it was estimated that in Norway as a whole there was 8300 man-years in the core aquaculture production (breeding, juvenile production and grow out), 3000 in slaughter and fish processing, and 940 in trade and export (Johansen *et al.*, 2020). In sum, this means that the basic aquaculture value chain consisted of about 12 000 man-years. Suppliers were however estimated to employ around 30 000 man-years to deliver their services, goods and equipment to the aquaculture value chain. As the aquaculture production in Norway has increased over time, increased employment has especially come as an economic ripple effect with the suppliers (Johansen *et al.*, 2020). The core aquaculture production has also seen a big relative growth in employment, but this has been much smaller in absolute terms, while slaughter and processing and trade and export have had more stable employment figures (op cit.).

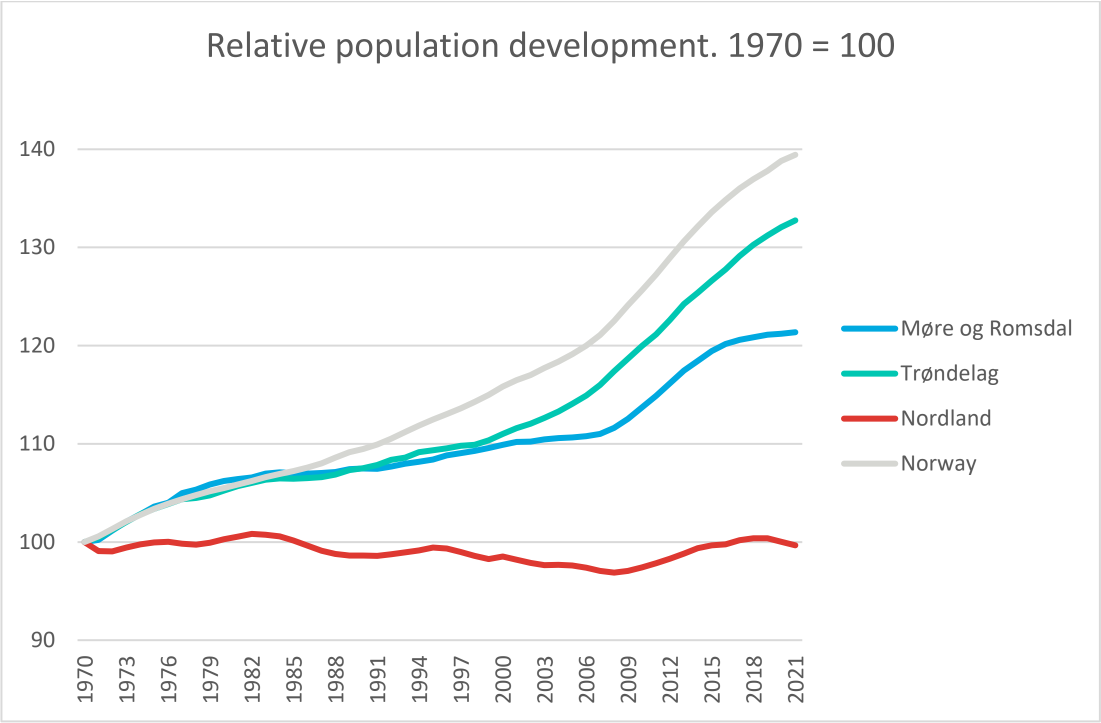

**Figure 6.4. Relative population development in Norway and the three counties bordering the Norwegian Sea ecoregion, during 1970–2021. Source: Statistics Norway, 2021a.**

Aquaculture has been considered important for rural development in Norway since the first Aquaculture Act was decided in 1973, and the regional distribution of benefits and burdens is still an important policy objective (Hersoug *et al.*, 2019; 2021). Aquaculture is to a large degree a rural and coastal industry, both in terms of where most workers are (Tveterås *et al.*, 2019), and in terms of its relative importance for employment (Table 6.1). The number of jobs in traditional primary industries like fishing and agricultural farming has on average gone down, making jobs in "new" industries like aquaculture even more welcomed. Aquaculture is also seen as one of the few industries that can create high-paying jobs in coastal communities in future (Tveterås *et al.*, 2019, page 115), and provide income for both private consumption and public welfare.

**Table 6.1. The aquaculture industry's share of employment by centrality class (%). Source: NOU (2020a).**

| **Centrality class**[1] | **1** | **2** | **3** | **4** | **5** | **6** | **Norway** |
|---|---|---|---|---|---|---|---|
| Aquaculture's employment share (%) | 0.0 | 0.1 | 0.0 | 0.4 | 1.1 | 3.6 | 0.3 |

**1) 1 is most central and 6 most rural.**

The concentration of ownership of the industry, larger and fewer slaughter plants and administrative centres, and more automated operations have all contributed to a more skewed geographical distribution of the income and jobs from salmon farming (Hersoug *et al.*, 2019; Hersoug *et al.*, 2021). Many coastal municipalities have over the years argued for mechanisms that ensure that all municipalities with aquaculture farms should get "a reasonable share" of the economic benefits from aquaculture (Isaksen *et al.*, 2012). In 2009 many formally organized themselves in the "Network of fjord and coast municipalities" (NFKK, 2019). As of May 2021, the NFKK had 75 municipalities as members[1]. The municipalities are important for aquaculture development as they make coastal area plans, and fish farms must be placed in areas set aside for aquaculture in the plans (or be granted an exemption from the plan by the municipality). The NFKK cite as

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[1] http://nfkk.no, visited 29 May 2021.

their biggest victory the establishment of the Aquaculture Fund in 2016 (NFKK, 2019). The fund is not a fund in the strictly financial sense, where assets are kept to give a return. Rather, as is explained in Section 4, a share of fees paid by companies for new aquaculture production capacity is put into the fund and paid out over a two-year period to municipalities and counties that have salmon farms.

The other more or less direct income municipalities have from aquaculture companies is through the possibility of levying property tax on real estate. In 2009, it was opened up for including the value of the fish farms as a basis for estimating property tax. But only the value of the physical capital, not the value of the fish itself. Although no recent or exact estimates of it exists (Ministry of Trade, Industry and Fisheries, 2019; page 56), it is clear that the property taxes from fish farms make up very modest sums. In 2012, it was estimated to be between 11–23 million NOK totally in Norway (Isaksen *et al.,* 2012).

From 2021, a new production tax on slaughtered salmon of 0.4 NOK/kg shall be levied and go to the municipalities where the fish was farmed. The share of the fees for new production capacity that goes to the municipalities will however also be reduced, from 80% to 40%. In sum, it is still clear that compared to the situation before 2016, the municipalities are getting a much larger share of the value-added in aquaculture than before. Whether this will give more areas for aquaculture in municipal coastal-zone planning is however not clear (Hersoug *et al.,* 2021). In their area planning the municipalities must consider and trade-off all relevant interests, including for the environment, industrial activities, recreation and more (op cit.). Although no national systematic assessment has been done, it seems likely that nature-based recreation and second home owners have got a stronger position compared to aquaculture over the last couple of decades (Hersoug and Johansen 2012; Young *et al.,* 2019; Hersoug *et al.,* 2021,).

## 6.3 Value of aquaculture

The added value of an industry is the difference between the total sales sum for its products and the total cost of the physical inputs used to make the products. The value added is shared between employees (pay wages), money lenders (pay interests on loans), the authorities (pay net taxes) and owners (pay dividends and/or increase the equity of the company).

Value-added per employee in aquaculture in Norway was estimated at around 3.75 million NOK in 2019 (Johansen *et al.,* 2020). This is much higher than the national average of 1.1 million NOK per employee (not including the petroleum industry), and also much higher than the 1.6 million NOK per employee in fisheries.

The total value added of Norwegian aquaculture has increased recently. For the core aquaculture value chain, the total value added was 36 billion NOK in 2019, while only 10 billion NOK in 2012 (Johansen *et al.,* 2020). Including the ripple effects in the supplier industries, the total value added in 2019 was 70 billion NOK compared to 33 billion NOK in 2012. Higher international prices for salmon explains most of this. The high prices have also led to salmon exports dominating the total seafood exports. In 2020, the total seafood export value from Norway was nearly 106 billion NOK, and aquaculture made up 70% of this (Norwegian Seafood Council, 2021). In terms of volume, on the other hand, aquaculture was less than 45% of the total seafood export.

Recent figures of value added from aquaculture is not available on the county level, only for fisheries and aquaculture combined. The value-added for fisheries and aquaculture combined do however indicate the status of aquaculture as a regionally important industry, and its importance in the Norwegian counties bordering the Norwegian Sea ecoregion. Note that nationally, the value-added of the fisheries value chain was smaller than for the aquaculture value chain; 25 vs. 36 billion in 2019 (Johansen *et al.,* 2020). Fisheries and aquaculture combined made up 1.8% of the total value added in Norway in 2018, but in the county of Møre og Romsdal they made up 6.4%, in the county of Trøndelag 2.5% and the county of Nordland as much as 9.2% (NOU, 2020a).

In addition to the total level of value added, the distribution of it between company owners and employees, and also between private persons and the public. The share of the value added that has gone to the company owners have increased in recent years, but both wages, taxes and dividends have increased in nominal terms (Sustainability in aquaculture, 2021). As mentioned in Section 4, the issues around the distribution of benefits from aquaculture have led to the establishment of the Norwegian Aquaculture Fund and the introduction of a municipal production fee on produced salmon of 0.40 NOK per kg. Part of the fees paid for new salmon and trout licenses/production capacity is redistributed to the municipalities and counties that have sites for such farming, as explained in Section 4. The fees paid per tonne of new salmon farming production capacity in 2018 and 2020 have been very large compared to the fees paid previously and is at least in part fuelled by the increased profitability due to high export prices. The auction of the licenses in the "green round" announced in 2013 gave an average price of 55 million NOK per standard license of 780 tonnes MAB (maximum allowed biomass). This corresponds to a price of ca. 71 000 NOK per tonne MAB (Mikkelsen, 2019).

In the 2018 round for the allocation of new production capacity under the traffic light system (see Section 4), some of the new capacity was sold at a fixed price of 120 000 NOK per tonne. This was 2% out of the 6% capacity increase. All of the capacity was sold. In the auctioning of the rest of the new capacity, the average winning bid was about 196 000 NOK per tonne, while the highest winning bid was 252 000 NOK per tonne. The average price for new production capacity in 2018 was about 169 000 NOK per tonne MAB (Mikkelsen, 2019). The average price varied a lot between the different PZs, from 132 000 to 250 000 NOK per tonne. There are likely several reasons behind this big difference, but they have not been investigated systematically. In total, the sale of 23 500 tonnes of new production capacity in 2018 gave nearly 4 billion NOK. Of this, 80% (3.2 billion NOK) was put into the Norwegian Aquaculture Fund and redistributed to municipalities and counties with salmon farming sites.

In the 2020 round, only 1% out of the 6% capacity increase was sold at a fixed price. Now the fixed price was 156 000 NOK per tonne MAB. In the auction of the rest of the new capacity, the average winning bid was 219 000 NOK per tonne. In other words, the prices paid for new capacity in the 2020-auction was more than three times as high as the price paid in the green round in 2013. Like in the 2018 auction, the price in 2020 varied considerably between PZs, from 156 000 to 257 000 NOK per tonne. The sale of a total of 32 600 tonnes of new capacity gave 6.8 billion NOK, yielding an average price of ca. 209 000 NOK per tonne MAB (Norwegian Directorate of Fisheries, 2020).

With the introduction of the salmon production fee from 2020, it was also changed how much of the fees paid for new production capacity that goes into the Aquaculture Fund, from 80% to 40%. This will be for sales of new production capacity from 2022. The fees paid for new production capacity in 2020 goes in full to the state. For 2020 and 2021 it was decided to put 3.25 billion NOK into the Aquaculture Fund and transfer it to the municipalities and counties with salmon farming sites. If the production of salmon is 1.4 million tonnes per year, this will give an annual production fee to the municipalities of 560 million NOK. If the fees paid for new production capacity every two years is 6.8 billion NOK, it will correspond to an annual average transfer to the municipalities and counties of 1.36 billion NOK (6.8 * 0.40/2), making the total annual transfers ca 1.9 billion NOK.

While the production fee and redistribution of fees paid for new aquaculture production capacity clearly affect the regional distribution of the benefits from aquaculture, the profits and dividends that accrue to the owners are also important for this (Aanesen and Mikkelsen, 2019). Regional ownership of aquaculture companies may in some cases be decisive for the regional net benefits of aquaculture to be positive (op cit.).

A valuation study for Arctic Norway, including Nordland county, found that on average people were positive to more coastal aquaculture (Aanesen *et al.*, 2018). People living in the more urban areas of Arctic Norway were however much less positive than those in rural areas, and it is believed that the jobs that aquaculture can provide is important for the rural population's attitudes. Another study suggests that there are widespread concerns regarding both environmental impacts and distributional justice with respect to the salmon farming industry in Norway (Bailey and Eggereide, 2020) and that in Arctic Norway there is a strong division on the social acceptability of the industry. The perceptions of the aquaculture industry of the populations in two municipalities in Nordland county was studied by Bjørkan and Eilertsen (2020). It concluded that the general public there thinks the aquaculture industry has a positive socio-economic effect on their municipalities. The general public thinks that there are negative environmental impacts, but that the access to space for themselves and also others, like fisheries and tourism, are not much affected by aquaculture. Fishers, do however have a negative perception of aquaculture.

From a national Norwegian viewpoint, the foreign ownership of the Norwegian aquaculture industry is also relevant to the distribution of the benefits from aquaculture. This was estimated to 35% in 2018 (Nøstbakken and Selle, 2019). The accumulated foreign ownership among the 20 biggest companies was higher, at 47%.

## 6.4 Sales

The value of sales of aquaculture species is of course linked to production volume for each species or species group through the average price received. The price can vary considerably over time, and even within rather short time spans, as illustrated through the export price per week for farmed salmon (Figure 6.5). Still, just like for the volume of production, Atlantic salmon dominates in value of sales, with rainbow trout as the second most valuable production. This goes for Norway as a whole as well as for the counties bordering the Norwegian Sea ecoregion (Tables 6.2, 6.3, 6.5 and 6.7). These counties are the top three counties in Norway in terms of the total production of salmonids, but while the production in counties od Trøndelag and Møre og Romsdal is about equally large, the production in the county of Nordland adds another 50%.

Also, for other fish species than salmon and rainbow trout, the Norwegian Sea ecoregion has a considerable share of national sales value (Table 6.3). Table 6.4. gives national figures for sales of other fish species. For Nordland county, a large share comes from aquaculture production based on wild-caught Atlantic cod. The county of Møre og Romsdal has no production of other fish species.

For sales of molluscs, crustaceans and echinoderms the counties bordering the Norwegian Sea ecoregion also dominate nationally, and especially the counties of Trøndelag and Nordland (Table 6.5). Nationally, the production of blue mussels dominates this group (Table 6.6).

Data on sales of farmed algae is not openly available by county, but only for Norway as a whole, by species (Table 6.7), but the data on number of licenses with production (Table 6.8) indicate that the Norwegian Sea ecoregion, and especially Nordland county, probably account for a considerable share of national production.

The overview presented here does not include data on sales of roe, brood fish or juveniles, but such data are openly available from the Norwegian Directorate of Fisheries.

**Table 6.2.Value of slaughtered salmon, rainbow trout and sea trout in 2019, by county. Counties bordering the Norwegian Sea ecoregion are in bold. Value in 1000 NOK. Source: Norwegian Directorate of Fisheries, 2021.**

| County | Atlantic salmon | Rainbow trout | Trout | Total |
|---|---|---|---|---|
| Troms and Finnmark | 14 817 628 | 0 | 0 | 14 817 628 |
| **Nordland** | **15 335 444** | **218 894** | **0** | **15 554 338** |
| **Trøndelag** | **10 021 831** | **116 661** | **0** | **10 138 492** |
| **Møre and Romsdal** | **9 548 776** | **579 532** | **0** | **10 128 308** |
| Vestland | 12 610 215 | 2 480 756 | 5000 | 15 095 971 |
| Rogaland | 4 502 162 | 61 998 | 1490 | 4 565 650 |
| Other counties | 1 153 977 | 6930 | 6089 | 1 166 996 |
| **Total** | **67 990 034** | **3 464 771** | **12 578** | **71 467 383** |

**Table 6.3. Total value of sale of other fish species in 2019, by county, from farmed and wild-caught fish. Counties bordering the Norwegian Sea ecoregion are in bold. Value in 1000 NOK. Source: Norwegian Directorate of Fisheries, 2021.**

| County | Farmed1) | Wild2) | Total |
|---|---|---|---|
| Troms og Finnmark | 1715 | 0 | 1715 |
| **Nordland** | **15 178** | **25 381** | **40 559** |
| **Trøndelag** | **10 552** | **0** | **10 552** |
| **Møre and Romsdal** | **0** | **0** | **0** |
| Sogn and Fjordane | 8016 | 0 | 8016 |
| Hordaland | 2500 | 0 | 2500 |
| Rogaland and other counties | 175 016 | 481 | 175 497 |
| **Total** | **212 978** | **25 862** | **238 840** |

1) **Production based on hatchery produced juveniles.**

2) **Production based on wild-caught fish.**

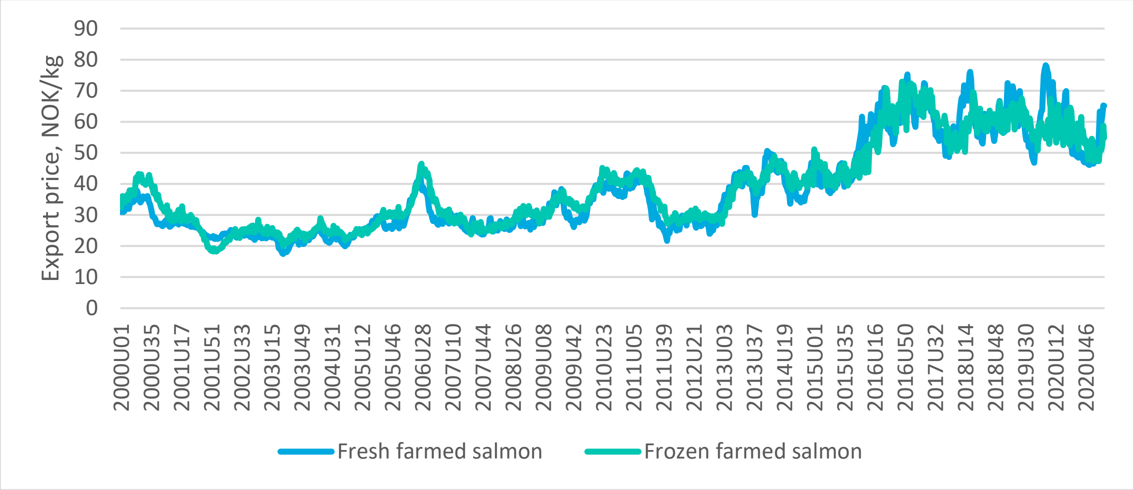

**Figure 6.1. Average price for farmed salmon exported from Norway, by week, NOK/kg. Source: Statistics Norway: https://www.ssb.no/statbank/table/03024.**

**Table 6.4. Total value of sale of other fish species in 2019, by species, from farmed and wild-caught fish. Value in 1000 NOK. Source: Norwegian Directorate of Fisheries, 2021.**

| Species | Farmed[1)] | Wild[2)] | Total |
|---|---|---|---|
| Atlantic cod | 0 | 25 381 | 25 381 |
| Arctic char | 30 144 | 481 | 30 625 |
| Atlantic halibut | 154 516 | 0 | 154 516 |
| Other species | 28 317 | 0 | 28 317 |
| **Total** | **212 978** | **25 862** | **238 840** |

[1)] **Production based on hatchery produced juveniles**

[2)] **Production based on wild-caught fish.**

**Table 6.5. Gross sale of molluscs, crustaceans, and echinoderms for consumption in 2019, by county. Counties bordering the Norwegian Sea ecoregion in bold, : confidential. Value in 1000 NOK. Source: Norwegian Directorate of Fisheries, 2021.**

| County | Value |
|---|---|
| Finnmark og Troms | : |
| **Nordland** | **7586** |
| **Trøndelag** | **16 606** |
| **Møre and Romsdal** | **2766** |
| Sogn and Fjordane | 301 |
| Hordaland | 1093 |
| Rogaland | : |
| Other counties | : |
| **Total** | **28 665** |

**Table 6.6. Gross sale of molluscs, crustaceans and echinoderms for consumption in 2019, by species. Value in 1000 NOK. Source: Norwegian Directorate of Fisheries, 2021.**

| Species | Value |
|---|---|
| Blue mussel (*Mytilus edulis*) | 24 523 |
| King scallop (*Pecten maximus*) | 363 |
| Oyster | 933 |
| Other species[1)] | 2846 |
| **Total** | **28 665** |

**[1)]Other species: lobster, crayfish etc.**

**Table 6.7. Harvesting of farmed algae in Norway in 2019, by species. Quantity in tonnes. Value in 1000 NOK. Source: Norwegian Directorate of Fisheries, 2021.**

| Species | Quantity | Value |
|---|---|---|
| Sugar kelp *(Saccharina latissima)* | 73 | 2599 |
| Winged kelp *(Alaria esculenta)* | 44 | 1755 |
| *Other species*[1)] | 0 | 5 |
| **Total** | **117** | **4359** |

**[1)]Other species: Dulse (*Palmaria palmata*), Nori nei (*Porphyra* spp)**

**Table 6.8. Number of licenses with production of algae in 2019, by county. Counties of the Norwegian Sea ecoregion are in bold. Source: Norwegian Directorate of Fisheries, 2021.**

| County | Licences |
|---|---|
| Finnmark | 0 |
| Troms | 0 |
| **Nordland** | **56** |
| **Trøndelag** | **10** |
| **Møre and Romsdal** | **3** |
| Sogn and Fjordane | 25 |
| Hordaland | 63 |
| Rogaland | 0 |
| Other counties | 9 |
| **Total** | **166** |

# 7 Interaction of environmental, economic and social drivers

The drivers for the development of aquaculture in Norway have clearly been manifold. The overall development is the product of the combined efforts of industry actors, authorities, researchers, and also other actors both in Norway and abroad. Some of the research and development has surely come out of curiosity-driven personal efforts. Others have had personal commercial interests, concerns for local or national societal development, for the environment, or for own or others use of the areas where fish farming takes place.

Since the 2013 round, environmental impact on wild salmon populations and the companies' willingness to pay for new production capacity and licenses have been the most important criteria, formalized through the traffic light system. To achieve a more predictable system for growth in aquaculture production, while taking environmental sustainability into account (Ministry of Trade, Industry and Fisheries, 2015), the traffic light system was implemented in 2017 for the adjustment of production capacity for salmon, sea trout and rainbow trout aquaculture.

A number of other sectors operate in the coastal regions of the Norwegian Sea and provide a regional context for both management and further development of aquaculture (Sandersen and Kvalvik, 2015; Bailey and Eggereide, 2020). Interactions with other sectors include both direct interactions through competition for space, and indirect interactions through impacts on the environment and biological systems, as well as social and economic interactions across local and national scales (Sandersen and Kvalvik, 2015; Olaussen, 2019; Bjørkan and Eilertsen, 2020; Hersoug *et al.*, 2021). Significant coastal marine sectors include commercial fisheries, recreational fisheries, tourism, shipping, energy and mining in addition to aquaculture.

The importance of the different sectors varies between the PZs. For instance, fisheries catches in the Norwegian Sea PZs ranged from an annual average of 10 600 tonnes in PZ 7 to 169 700 tonnes in PZ 9, for the period 2011–2019 (Table 7.1). Hence, the annual aquaculture production exceeds the fished biomass in PZs 5–8 but is lower than the fished biomass in PZ 9. However, most of the catch is taken by the larger vessels ( > 15 m) in the offshore part of these PZs, as different fishing regulations limit large vessels to fish in coastal zones (e.g. general non-trawling zones for demersal trawling stretching 12 nautical miles from the coast, and no fishery by vessels > 15 m inside the coastally defined 'fjord lines', Table 7.1). The relative importance of coastal fisheries (e.g. vessels < 15 m) in terms of proportion of total catch increases from PZ 5 (on average 19% of the catches) to PZ 9 (on average 42% of the catches, 2011–2019, source: Norwegian Directorate of Fisheries). Norway also has the highest participation rate in marine recreational fisheries in Europe (Hyder *et al.*, 2018), and a total of 522 tourist fishery companies are registered in PZ 5–9 (Source: Statistics Norway). The Norwegian Sea PZs also include some of the largest rivers for the recreational fishery for salmon, with annual revenues, on a national scale, of 1.3 billion NOK (Bailey *et al.*, 2020). Interactions between aquaculture and fisheries are both related to access to space and fishing grounds and the possible impact on the behaviour and physiology of wild fish living close to fish farms (Olaussen, 2019; Bjørkan and Eilertsen, 2020; Barrett *et al.*, 2018; Bjørn *et al.*, 2009). Also, the effects of delousing agents on non-target species, and harvested coastal shrimp populations specifically, remains a topic of controversy and interest (Olaussen, 2019; Bjørkan and Eilertsen, 2020).

Table 7.1. Annual average catches (in 100 000 tonnes) by fisheries in PZs 5–9, by coastal vessels ( < 15 m) and large vessels ( > 15 m), for the period 2011–2019. (Source: Norwegian Directorate of Fisheries)

| Vessel size | PZ5 | PZ6 | PZ7 | PZ8 | PZ9 |
|---|---|---|---|---|---|
| < 15 m | 109.5 | 77.7 | 36.2 | 112.1 | 708.0 |
| > 15 m | 450.1 | 222.4 | 70.0 | 236.7 | 989.1 |
| **Total** | **559.6** | **300.1** | **106.2** | **348.8** | **1697.1** |

Within the energy sector, the aquaculture PZs include both hydropower and petroleum activities. Around 513 hydropower production facilities (30% of all hydropower facilities in Norway, 24% of hydropower energy production) is based in the PZs (Source: The Norwegian Water Resources and Energy Directorate). The hydropower regulation of rivers has reduced habitat quality and inflicted high mortalities to wild salmon, to which also aquaculture adds mortality (Skaala *et al.,* 2014; Forseth *et al.,* 2017). Hydropower also alters circulation patterns and distribution of planktonic organisms within fjords (Kaartvedt and Svendsen, 1990; Myksvoll *et al.,* 2014), although to which extent this influence fjord water ventilation and capacity for salmon farming, and drift patterns of salmon lice, remains an open question (Askeland Johnsen, pers. comm.).

Petroleum activity is mostly located outside the PZs, although both seismic and electromagnetic surveys extend into the more offshore parts of these zones. Offshore wind farming is a sector in development, and areas relevant to future wind farming are already identified in PZs 5–9. While areas for floating installations are offshore and in the deeper waters, areas for fixed installations are closer to both shore and current aquaculture production (Source: www.BarentsWatch.no). Both the expected increase in offshore wind farming and the development of offshore aquaculture is expected to increase areal conflicts and trade-offs between these sectors.

Regulated fairways cover extensive areas along the coast, both inshore and offshore of the Norwegian Sea ecoregion (Source: www.barentswatch.no). Due to both fisheries, aquaculture, petroleum and transportation of goods and people, shipping activity is high (e.g. 41% of total sailed distances across all PZs in 2019, based on AIS). Sailed distances increased in these areas by 43% in the period 2015–2019 (from 14.89 to 21.36 million nautical miles per year. Source: Norwegian Coastal Administration).

Finally, land-based mining activity with deposits in fjords has occurred in several fjords within the Norwegian Sea ecoregion and is still occurring in four fjords (Frænfjorden, Ranfjorden, Tysfjorden and Kjøpsviksundet) within the Norwegian Sea ecoregion, while a fifth location is in planning (Tosenfjorden, source: www.norskeutslipp.no). The disposals consist of both environmental pollutants, particulate matter and sand and gravel, with impacts on the fjord environments kilometres from the disposal site (Harman *et al.,* 2020).

# 8 Future projections and emerging threats and opportunities

There is an increasing global demand for healthy food, and marine aquaculture is highlighted as one of the sectors with the highest potential of providing foods of high nutritional value (FAO, 2020). The potential for future aquaculture growth in the Norwegian Sea ecoregion is on short-term depending on the production of Atlantic salmon and rainbow trout that constituted 99.5% of the total aquaculture production in 2019 (Section 3), but further growth will also depend on the development of the aquaculture industry, and how the industry interacts with the ecosystem and other sectors operating in the same areas.

## 8.1 Diversifying the industry

Diversification of the aquaculture industry in Norway and the Norwegian Sea ecoregion can mainly occur through two different mechanisms. The first is that new production concepts and technologies for growing out of salmonids are developed and implemented, with other finfish included. The second mechanism is diversification through expanding or starting production of low trophic species.

### 8.1.1 Finfish aquaculture

**Atlantic salmon and rainbow trout**

Today, salmonids are mainly farmed in open net pens which are considered to be the most feasible way of producing fish in large numbers. Due to the environmental impacts related to this production method, other production forms are explored. The use of closed systems, either in the sea or on land, has been an approach to solve challenges with salmon lice and escapes, and other hazards associated with open cage aquaculture. However, studies have shown that problems with fish welfare (water quality and disease/stress) may increase in closed systems (Noble *et al.*, 2018). Moving fish farms on land will also require the development of large areas along the coast and energy consumption will increase substantially due to the need for power to operate the facilities (e.g. pumping seawater). In contrast to sea-based farms, the impact of building constructions on land is irreversible. As non-developed areas are in decline and energy consumption should rather be reduced than increased, moving marine aquaculture on land should be thoroughly revised before being implemented on a larger scale.

Another option would be to secure further expansion of the production capacity by establishing systems offshore. A Norwegian interdepartmental group with inputs from Norwegian governmental directorates and a university reported on needs and possibilities for adapting relevant law and regulations accordingly (https://www.regjeringen.no/no/dokumenter/havbruk-til-havs/id2625352/). Furthermore, the Norwegian Fisheries Directorate in collaboration with the Institute of Marine Research, Norway, has identified areas and characterized their environment beyond 1 nm off the coast (https://www.fiskeridir.no/Akvakultur/Dokumenter/Rapporter/Kartlegging-og-identifisering-av-omraader-egnet-for-havbruk-til-havs). As a basis for this report IMR has delivered three reports on i) relevant physical environmental conditions and ecosystem impacts (https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2019-41), ii) fish welfare and environmental requirements (https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2019-37), and iii) offshore spreading and exchange of salmon lice (https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2019-58). Environmental concerns are related to e.g. a comparison of the experimentally measured maximum currents allowing good fish welfare vs. current conditions at sea, wave heights vs. fish welfare and installations resilience, exchange of salmon lice to and from coast and overlap with valuable and vulnerable areas. Areas are identified and temporarily development licences have been granted (e.g. https://www.fiskeridir.no/Akvakultur/Nyheter/2021/den-forste-soknaden-om-klarering-av-lokalitet-i-norskehavet), and conflict between an offshore fish farm and petroleum industry over areas has already occurred (https://www.fiskeridir.no/Akvakultur/Nyheter/2021/oppdatering-av-soknaden-om-klarering-av-lokalitet-i-norskehavet).

### Other marine finfish

In the later years, there has been a growing interest in increasing the production of other marine finfish species such as halibut and Atlantic cod (Torrissen *et al.*, 2018), but the production is still at a low level (around 2000 tonnes in 2019). However, aquaculture with these fish species will also meet challenges with genetic impact on wild populations, disease transmission as for Atlantic salmon (Bjørn *et al.*, 2021).

### Sustainable fish feed

For all high trophic fish species, there is limited availability of fish oil and marine proteins for fish feed production. It is apparent that future finfish culture cannot depend on fishmeal and fish oil from reduction fisheries. However, the inclusion of more plant ingredients increases the use of freshwater, arable land and phosphorus (Malcorps *et al.*, 2019) and increases feed/food competition. In addition, more than 80% of the greenhouse gas emissions from Atlantic salmon production in Norway are attributed to the feed ingredients (Winther *et al.*, 2020). In order to lower the footprint of salmon farming, R&D efforts are focused on so-called third-generation feed ingredients. These ingredients do not require large inputs like arable land, fertilizer, freshwater, but instead, focus on valorising organic streams produced in the food chain. Examples are insects fed on organic waste, yeast fed on cellulose-rich waste material, microalgae fed on captured $CO_2$. Also, low-trophic feed material produced in the oceans, like seaweed of bivalves that do require much input, receive a lot of attention.

## 8.1.2 Low-trophic species

Due to the reduced availability of fishmeal worldwide, the increase in production of fed organisms in aquaculture most likely will slow down, and other non-fed aquaculture species, so-called low trophic organisms, should be considered (FAO, 2020; Naylor *et al.*, 2021). In addition to being valuable protein sources for human consumption, these organisms also have the potential to provide ecosystem services (e.g. improve water quality) and non-food products (e.g. fertilizers, construction materials etc.) (see Naylor *et al.*, 2021, Weitzman 2019 and references therein). Molluscs and algae dominate the production of non-fed organisms and shelled molluscs accounted for 56.3% of the global marine and coastal aquaculture production in 2018 (FAO 2020). The production of non-fed organisms is negligible in Norway today and is dominated by blue mussel production. The main production of blue mussels in Norway is in PZs 6–8, but the production volume is still low, about 2000 tonnes, compared to the salmonid production, about 714 000 tonnes, in 2019. Norwegian kelp industry is in its infancy and of the 17 active licenses on macroalgae production, eight are in the Norwegian Sea ecoregion, but only 117 tonnes were harvested for sale in 2019 (not specified for PZ or county).

# 8.2 Need for the integrated ecosystem assessment

Future growth of the aquaculture industry in the Norwegian Sea ecoregion will require more space, likely cause increased impacts on the marine ecosystem, and elevate interactions and potentially escalate the conflict between aquaculture and other sectors. Currently, an aquaculture risk assessment is in place (Section 5), routinely updated to inform managers on impacts from a range of stressors associated with the aquaculture sector. However, no similar risk assessments are established for the other sectors operating in the coastal regions, or to assess risks from cumulative impacts across all the sectors. To support such cross-sector assessments, coastal Integrated Ecosystem Assessments (IEAs) are currently being developed through the CoastRISK project (Funded by the Norwegian Research Council, 2019–2023, project no. 299554). Priorities are given to develop: i) an indicator-based framework to inform on the status and development of physical environment and ocean climate, biological systems, and human activities with associated stressors and ii) a cumulative impact assessment (e.g. Pedreschi *et al.*, 2019), where impacts from aquaculture on the marine ecosystems will be assessed in combination with, and relative to, the other sectors. Ideally, both approaches should be expanded to also include ecosystem services and social and economic indicators, to allow assessments of synergies and trade-offs among coastal sectors and consequences across environmental, ecological, and socio-economic dimensions.

## 8.3 Effect of climate change

Gradual heating and expected heat waves (IPCC, 2019) affect aquaculture production directly through e.g. stress on cultivated species and indirectly through changes in environmental conditions (e.g. deoxygenation). This is a strong motivator for developing seasonal to annual and decadal prediction capability (Smith *et al.*, 2020). Harnessing earth system models with assimilation schemes allow optimal starting point for predictions into the near future (Counillon *et al.*, 2014; 2021). Adopting such predictions to assess risk and mitigation for industries such as aquaculture is on its way (e.g. https://www.climatefutures.no). On top of global warming, we find natural variability on multiple time and space scales. The observed temperature in the Norwegian Sea ecoregion is observed to peak in 2007 at almost 1.5°C above the long-term mean as a consequence of Atlantic Multidecadal Oscillations of 60–80-year cycles (ICES, 2019). In the western Barents Sea entrance, the average temperatures in the upper 50–200 m also reached a long-term peak in 2007 (ICES, 2020a).

The coastal heating reflects the open ocean temperatures as observed at multiple coastal hydrographic stations with the ecoregion. It results in less density of coastal water and consequently less frequent exchange with bottom water in fjords with sill and hence likely reducing the carrying capacity of aquaculture through deprived levels of oxygen (Aksnes, 2019). Despite the recent maximum in ocean temperatures, this is a transient and local halt in ocean temperature increase and the future condition in the ecoregion is predicted to be warmer than seen before from instrumental records.

Climate change can hamper sustainable growth in the aquaculture industry by amplifying and adding to other environmental challenges. Salmon lice-induced mortality in wild salmonid populations is identified as a major risk factor for further expansion. Higher temperatures will induce increased production of salmon lice larvae, decreased developmental time from non-infective nauplii to infectious copepods, and higher infectivity of copepodids. In a warmer climate, these three factors lead to a significant increase in the infection pressure from farmed to wild salmonids, where the infectivity of copepodids is the term with the highest sensitivity to temperature changes (Sandvik *et al.*, 2021). The total infection pressure gradually increases with increasing temperature, with an estimated twofold if the temperature increases from 9°C to 11°C. A good management plan is therefore necessary to ensure environmental sustainability and further growth in the aquaculture industry in a warmer climate. To mitigate the increasing infection pressure on wild salmonids with higher temperatures, there is a need to minimize the release of salmon lice from farmed fish (Sandvik *et al.*, 2021).

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# 10 Data flow

The data flow schematic and data table (Figure 10.1 and Table 10.1, respectively) were developed to implement the FAIR (Findable, Accessible, Interoperable, Reusable) data principles, best practices for data management and ICES data policy and to facilitate the uptake of the ICES Transparent Assessment Framework (TAF). The objective is to promote transparency and accessibility of the data sources associated with the Aquaculture Overview. Additionally, ICES uses the information to match the timing of the reports to the data availability of the given ecoregions.

The data flow schematic illustrates the overall process from data collection to publication of the Aquaculture Overview. It is supported by the data table, which contains more detailed information on the data; as indicated in the table, some data are only available in Norwegian. Both products were drafted and presented at the Workshop for the Norwegian Sea Aquaculture Overview (WKNORAO) for feedback. A generalized data flow chart and data table can be found in the technical guidelines, which will serve as templates for future Aquaculture Overviews.

### Figure 10.1 walk-through

The data flow begins with the “**data collection**”, which is handled by the Directorate of Fisheries in Norway. It collects information on e.g. licenses and localities and receives production data from the aquaculture producers. The producers are under a legal obligation to submit this information on a monthly basis. Both types of data undergo quality checks pursuant to the EuroStat Code of Practice and Section 5 of the Norwegian Statistics Act (see also national programme for official statistics) prior to their inclusion in the Directorate’s database. With the exception of sensitive data, the database contents are publicly available.

This concludes the external process and initiates the “**definition of data required**”. The Aquaculture Operational Group composed of the lead author, Advisory Committee (ACOM) leadership, the Aquaculture Steering Group (ASG) Chair, ICES secretariat and others, agree on the scope of the Aquaculture Overview with emphasis on the technical guidelines. An ICES standard request is issued, leading to the “**data extraction**”. Relevant ICES expert groups, i.e. those operating under the ASG, are encouraged to provide input and resources for the Aquaculture Overview. Data are extracted and adapted to ecoregion and PZ as necessary.

A workshop is organized to complete a workshop report based on the extracted data, marking the first step of the “**Aquaculture Overview**”. The report is peer-reviewed by the Review Group (RG), Advice Drafting Group (ADG) and ACOM. They evaluate it as a whole, including the quality of the data (see ICES best practices for data management, Section 1.4). Any issues are brought up with the authors. When the Aquaculture Overview is approved, it is published.

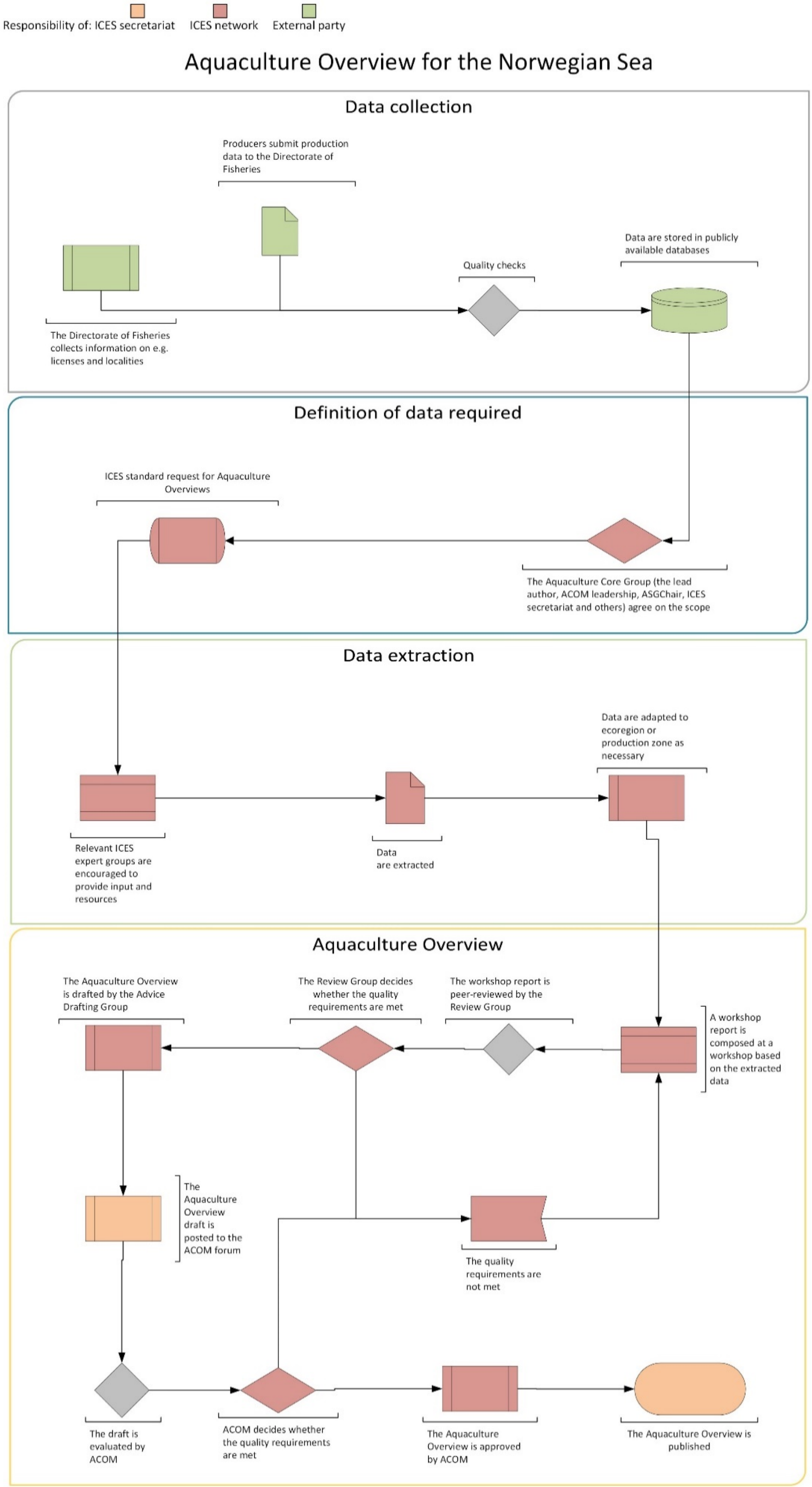

**Figure 10.1. Data flow schematic illustrating process from data collection to publication of Aquaculture Overviews.**

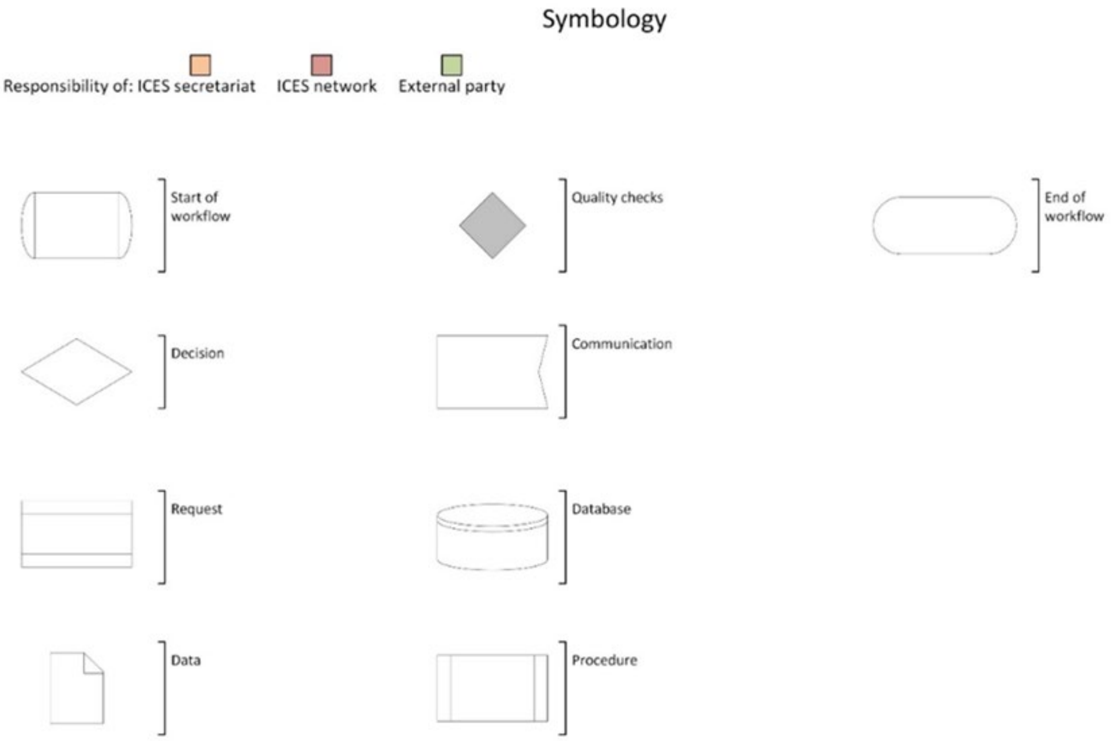

Figure 10.1. (continued) Data flow schematic illustrating process from data collection to publication of Aquaculture Overviews.

**Table 10.1. Data table containing more detailed information on the data associated with the present Aquaculture Overview.**

| Section | Authors | Data | Description | Location | Date of download | Language | Source | Ownership | Accessibility | Access rights | Access duration | Time scale | Availability | Update frequency | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Introduction | Frode Vikebø, Solveig Trongaard | **Figure 1.1** | Ecoregion | https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/2021/EcosystemOverview_NorwegianSea_2021.pdf | 14-Apr-21 | English | https://www.ices.dk/advice/ESD/Pages/Ecosystem-overviews.aspx | ICES | Open | N/A |  | N/A |  | N/A |  |
|  |  | **Figure 1.2** | Bathymetric map | https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2019-58 | 20-Oct-20 | Norwegian | Sætre 2007 (IMR): "The Norwegian coastal current: oceanography and climate", Tapir Academic Press. | Institute of Marine Research | Open | N/A |  | N/A |  | N/A |  |
|  |  | **Figure 1.3** | Production zones | https://lovdata.no/dokument/SF/forskrift/2017-01-16-61 | 14-Apr-21 | Norwegian | https://lovdata.no/dokument/SF/forskrift/2017-01-16-61 | Ministry of Trade, Industry and Fisheries | Open | N/A |  | N/A |  | N/A | The production zones in the the Norwegian sea is shown in red |
|  |  | **Figure 1.4** | Fjord circulation | https://doi.org/10.1016/j.ecss.2019.106392 | 22-Mar-21 | English | Aksnes et al. 2019 | Estuarine, Coastal and Shelf Science | Open | N/A |  | N/A |  | N/A |  |
| 2. Description and location of marine aquaculture activities and practices | Terje Svåsand, Mette Skern-Mauritzen | **Table 2.1** | Aquaculture sites by county in Norway | https://www.fiskeridir.no/English/Aquaculture/Statistics | 15-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 2.1** | Production sites with biomass by species | https://open-data-fiskeridirektoratet-fiskeridir.hub.arcgis.com/ | 10-Jun-21 | Norwegian | Open map source from the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  |  |  |  |  |
|  |  | **Figure 2.2** | Atlantic salmon farm |  |  |  | Photo: Erwann Legrand / Institute of Marine Research, Norway | Erwann Legrand / Institute of Marine Research, Norway |  |  |  |  |  |  |  |
|  |  | **Figure 2.3** | Blue mussel farm |  |  |  | Photo: Tore Trohmeier, Institute of Marine Reserach | Tore Trohmeier, Institute of Marine Reserach |  |  |  |  |  |  |  |
| 3. Production over time | Mette Skern-Mauritzen, Eirik Mikkelsen, Terje | **Table 3.1** | Aquaculture production in Norwegian Sea ecoregion (by county and total) | https://www.fiskeridir.no/English/Aquaculture/Statistics | 15-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure.3.1** | Production of Atlantic salmon, rainbow trout and other species) in Norway from 1980-2019 | https://www.fiskeridir.no/English/Aquaculture/Statistics | 15-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 3.2** | Juvenile fish production in Norway in 2019 | https://www.fiskeridir.no/English/Aquaculture/Statistics | 15-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 3.2** | Aquaculture production in the Norwegian Sea ecoregion | https://www.fiskeridir.no/English/Aquaculture/Statistics | 15-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 3.3** | Production of juvenile Atlantic salmon and rainbow trout in the Norwegian Sea ecoregion | https://www.fiskeridir.no/English/Aquaculture/Statistics | 15-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
| 4. Policy and legal foundation | Terje Svåsand, Eirik Mikkelsen | **Table 4.1** | Aquaculture licenses by county in Norway | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 4.2** | Share of licenses with production in 2019 | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 4.3** | Aquaculture licenses for Atlantic salmon, trout and rainbow trout by county in Norway and type of | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 4.4** | Aquaculture licenses in Norway for other fish species than Atlantic salmon, trout and rainbow trout, by | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 4.1** | Illustration of environmental impacts of fish farming in open net pens and identified hazards |  |  |  | Institute of Marine Research | Institute of Marine Research |  |  |  |  |  |  |  |
| 5. Ecosystem/environment interactions | Ellen Sofie Grefsrud, Terje Svåsand |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6. Social and economic context | Eirik Mikkelsen | **Figure 6.1** | Production costs, salmon+, Norway | https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Loennsomhetsundersoekelse-for-laks-og- | 15-Apr-21 | Norwegian | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 6.2** | Profits per kg, salmon+, Norway | https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Loennsomhetsundersoekelse-for-laks-og- | 15-Apr-21 | Norwegian | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 6.3** | Operating margin, salmon+, Norway | https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Loennsomhetsundersoekelse-for-laks-og- | 15-Apr-21 | Norwegian | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 6.4** | Population development, Norway & Norwegian Sea ercoregion counties | https://www.ssb.no/statbank/table/06913 | 15-Apr-21 | Norwegian | Statistics Norway (https://www.ssb.no) | Statistics Norway | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.1** | The aquaculture industry's share of employment by centrality class | https://www.regjeringen.no/no/dokumenter/nou-2020-12/id2776843/ | 15-Apr-21 | Norwegian | Figur 2.18 in NOU, 2020a. Næringslivets betydning for levende og bærekraftige lokalsamfunn (The industry's importance for vital and sustainble local communities) Norwegian Official Report NOU 2020:12. | Ministry of Trade, Industry and Fisheries, Ministry of Local Government and Modernisation | Open | N/A |  | Annual |  | N/A |  |
|  |  | **Table 6.2** | Value of slaughtered salmon, rainbow trout and sea trout in 2019, by county | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.3** | Total value of sale of other fish species in 2019, by county, from farmed and wild-caught fish | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Figure 6.5** | Average price for farmed salmon exported from Norway, by week | Statistics Norway: https://www.ssb.no/statbank/table/03024 | 15-Apr-21 | Norwegian | Statistics Norway (https://www.ssb.no) | Statistics Norway | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.4** | Total value of sale of other fish species in 2019, by species, from farmed and wild-caught fish. | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.5** | Gross sale of molluscs, crustaceans and echinoderms for consumption in 2019, by county | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.6** | Gross sale of molluscs, crustaceans and echinoderms for consumption in 2019, by species | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.7** | Harvesting of farmed algae in Norway in 2019, by species | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
|  |  | **Table 6.8** | Number of licenses with production of algae in 2019, by county | https://www.fiskeridir.no/English/Aquaculture/Statistics | 13-Apr-21 | Norwegian and English | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries | Open | N/A |  | Annual |  | Annually |  |
| 7 Interaction of environmental, economic and social drivers | Mette Skern-Mauritzen, Bjarte Bogstad, Ellen Sofie Grefsrud, Eirik Mikkelsen, Terje Svåsand, Frode Vikebø | **Table 7.1** | Annual average catches (in 100 000 tons) by fisheries in PZs 5 – 9 | https://www.fiskeridir.no |  |  | Official statistics provided by the Norwegian Directorate of Fisheries | Norwegian Directorate of Fisheries |  |  |  |  |  |  | Calculated from data delivered from the Norwegiean Directorate of Fisheries |
| 8 Future projections, and emerging threats and opportunities | Terje Svåsand, Bjarte Bogstad, Ellen Sofie Grefsrud, Mette Skern Mauritzen, Eirik Mikkelsen, Frode Vikebø |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Description of fields in Table 10.1.**

**Section: The given section of the report.**

**Authors: A full list of contributing authors of the given section.**

**Data: The figures and tables in the section as named in the report.**

**Description: A short description of what the figure/table illustrates.**

**Location: A link or similar directions for where the data can be found.**

**Date of download: When were the data downloaded.**

**Language: The language of the data.**

**Source: The source that the data originate from, e.g. surveys, assessments and producer reports.**

**Ownership: Who owns the data.**

**Accessibility: Who can access the data.**

**Access rights: If access is restricted, how can it be obtained.**

**Access duration: If access is granted, for how long does it last.**

**Time-scale: If applicable, which period do the data cover.**

**Availability: Are the data associated with a particular release date.**

**Update frequency: How often are the data updated.**

**Comments: Any other important information.**

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| Name | Institute | Country (of institute) |
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| Terje Svåsaand | Institute of Marine Research (IMR) | Norway |

# Annex 2: Resolutions

**2021/WK/ASG05** **Workshop on the Norwegian Sea Aquaculture Overview (WKNORAO)** chaired by Terje Svåsand*, Norway, and Henn Ojaveer*, ICES, will be established and will meet online during 23–25 March 2021 to:

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

b ) In collaboration with the ICES Data Centre, collate an overview of datasets and resources for the aquaculture overview in line with the FAIR data principles. This overview should categorize each of the resources with regards to availability, appropriateness, access rights, data format, accessibility, and other categories, as required; and

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

WKNORAO will report by 30 of April for the attention of the ACOM.

**Supporting information**

| | |
|---|---|
| Priority | Aquaculture is a high-priority topic for ICES. ICES work on aquaculture is part of a wider portfolio of work that seeks to advance and share scientific understanding of marine ecosystems and the services they provide, and to use this knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals.<br>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 Aquaculture Overviews (AOs) was initiated in 2019, with i) forming a core group consisting of representatives from ACOM leadership, SCICOM and Secretariat, and ii) agreeing on the directions and procedure of further work of the core group. Objectives and contents of AOs was agreed by ACOM, including the first ecoregion for which the AO will be published (Norwegian Sea), together with the steps in the process and time-line. One of the steps was to arrange a workshop in spring 2021. |
| Resource requirements | The lead author of the Norwegian Sea AO (Terje Svasand) 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 Norwegian Sea AO, as well as other interested scientists from the ASG and lead authors for Faroes and Celtic Seas AOs |
| 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: Historic development of aquaculture in Norway

Aquaculture in Norway goes back to the 1850s, when one started with hatching of trout to improve freshwater stocks (SNL, 2021), and in the 1880s experiments with saltwater species started with hatching of cod eggs, also with the idea to supplement natural stocks to improve abundance (Solemdal *et al.,* 1984). At the end of the 1800s, the first rainbow trout was imported from Denmark for aquaculture (SNL, 2021). In the early 1960s, Norwegian pioneers succeeded to habituate reared rainbow trout to salt water, and one also experimented with farming Atlantic salmon. Salmon was sold at higher prices than rainbow trout in the market, but it is not clear to what extent commercial concerns were driving the early pioneers of salmon farming (Hovland, 2014). The first salmon smolt was put in the sea in the late 1960s, and the first farmed salmon was slaughtered in 1971. The design of a relatively simple and cost-effective sea pen in the late 1960s was an important element for the early growth of sea-based farming, and the same principal technology is still dominating salmon farming today (Hersoug *et al.,* 2021).

From the first slaughtered Norwegian farmed salmon in 1971, the growth and interest was so large that already in 1972, the government appointed a commission to give advice on the regulation of the industry (Hovland and Møller 2010). They recommended a temporary Aquaculture Act, which was decided in parliament in 1973 (Hersoug *et al.,* 2019). It made an aquaculture license necessary, and also had restrictions and rules regarding pollution, the risk for spread of diseases, technical quality of the farm, and conflicts with others. Also concerns for the market conditions could be used to turn down license applications, as well as if a license would not be in line with "societal interests". Aquaculture was seen as a tool for regional development already when the Act of 1973 were being developed (op cit.), and in Norway the official preparatory documents matter for the interpretation of legal texts. The first permanent Aquaculture Act was decided in 1981, and it made the rural policy intentions even clearer by explicitly stating that fish farms should be placed for the largest possible rural policy impact, and also that preferably the owners of the farms should be the ones operating them. In the early years of salmon farming, it was thought that the waters in the northern part of Norway was too cold for salmon farming. This included the northern part of the Norwegian Sea ecoregion. But by 1981 one had learned different, and the northern region even got prioritized for new licenses in the first license round (Hersoug *et al.,* 2019).

As is explained in Section 4 on policy and legal foundation, the regulation of aquaculture is done based on the laws decided by the parliament, but also formal regulations based on the laws. These formal regulations are decided either by the government or a ministry. This facilitates a rather agile legal regulation. There has thus formally only been two other Aquaculture Acts since 1981, one decided in 1985 and one in 2005, but new or adjusted formal regulations have been decided quite often ( Mikkelsen *et al.,* 2018, Hersoug *et al.,* 2019). Over the years, many different concerns have affected aquaculture regulation in Norway. This regards both the criteria for the issuing of new aquaculture licenses, for the regulation of operations and other aspects, like the municipal production fee introduced in 2021 for salmon farming.

While it was possible to apply for a license at any time in the early years of the industry, from 1981 new licenses have only been issued through licensing rounds. Between 1981 and 2009, practically all new licenses were pre-ascribed to either specific counties or municipalities. This geographical binding was either purely political decisions, or based on analyses of where there was room for more aquaculture, or where the environmental impact or disease challenges were considered high (op cit.).

The limitations on ownership in the 1970s and early 1980s were loosened with a new government in 1982. Naturally, this led to some concentration of ownership and also more efficient production. By 1990 the growth in salmon production had surpassed market demand, and the industry was in big trouble. The industry made a sales organization, based on the principle that all the farmers sold salmon to it. The sales organization ended up freezing much salmon, hoping for better prices, but eventually it went bankrupt, taking down many salmon farmers as well. This led to further concentration and consolidation of the industry as the bankrupt companies were bought by the survivors. In the early 1990s, the EU made its firsts claims of dumping and subsidies, backed by farmers in Scotland and Ireland (Hersoug *et al.,* 2019). The EU was then, and still is, the most important market for Norwegian salmon. In 1996 the Norwegian government signed an agreement with the EU, and regulated fish production by feed quotas and other limitations on feeding, which lasted until 2004.

The first ordinary license round since 1985 came in 2002. For the rounds from 2002 up to 2013 the stated criteria for allocating new salmon farming licenses between applicants included their efforts or impacts on fighting fish diseases, limiting parasites and escapes, industrial ripple effects and regional development, companies' size, gender of owners or operators, and the impact on the Saami indigenous population. And also, the companies' willingness to pay for new licenses got increasingly important during this period. Hence, the stated criteria for allocating licenses have varied a lot. The companies awarded licenses in the 2002–2013 rounds were however not forced to deliver on the promises in their applications (Hersoug *et al.,* 2019).

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# Annex 4: Environmental interaction of aquaculture

## Introduction

The text describing the environmental interactions of salmon farming is mostly taken from the ICES Working Group on Environmental Interactions of Aquaculture (WGEIA) final report (ICES, 2020), Risk Report Norwegian Fish Farming 2021—knowledge base (Grefsrud *et al.*, 2021b), Kunnskapsgrunnlag for mulig påvirkning fra oppdrettstorsk og levendelagret torsk på villtorsk (Bjørn *et al.*, 2021) and references therein. The summary of the risk status in aquaculture PZs in the Norwegian Sea ecoregion is based on the risk assessment published in the Risk Report Norwegian Fish Farming 2021—risk assessment (Grefsrud *et al.*, 2021a) and Risk Report Norwegian Fish Farming 2021—knowledge base (Grefsrud *et al.*, 2021b) and references therein.

Section 5 is a summary of Annex 4.

## Salmonid farming

### Transfer of parasites virus and bacteria to wild fish populations

Parasites, virus, and bacteria that are naturally present in the marine environment can occasionally become abundant in aquaculture farms representing a risk of transfer to wild fish.

#### Parasites

The salmon louse *Lepeophtheirus salmonis* is the most abundant parasite that affects farmed Atlantic salmon in Norway and is considered as the major threat to wild salmon populations (VRL 2020). Other sea lice constituting problems for salmonids include various *Caligus spp.*, including *Caligus rogercresseyi* (Hamre *et al.*, 2013), and *Caligus clemnsi*.

The salmon louse is a naturally occurring ectoparasite that attaches to the skin of salmonids, feeding on the skin, blood, fat, and mucus (Pike and Wadsworth, 1999; Boxaspen, 2006). The lice have eight distinct stages separated by a moult, with the three first being free drifting in the water and the next five on the host (Johnson and Albright, 1991; Hamre *et al.*, 2013). The first two free drifting nauplii stages will only cause the lice to move away from the source. Once moulting into the copepodite stage, the lice become infective and need to find a salmonids to use as host. In the final stage the female lice produce several hundreds of eggs hatching into the first nauplius stage at temperature dependent intervals, typically repeating this more than ten times (Brooker *et al.*, 2018a). The duration of the free drifting period is from almost a month in relatively cold winter water temperature (~5°C) to 1–2 weeks in relatively warm summer water (~16°C).

The planktonic copepodites avoid low salinity water (Crosbie *et al.*, 2019) and accumulate at natural phenomena such as frontal regions/convergence of water and haloclines as well as along the littoral zone. This increases the likelihood of lice encountering and attaching to salmonids (reviewed in Brooker *et al.*, 2018a). There is a high variability of embayment, fjordic and coastal currents in both time and space that leads to patchiness in the levels and distribution of the planktonic lice (Penston *et al.*, 2004; Asplin *et al.*, 2014; Sandvik *et al.*, 2016). Even if the number of lice on an individual farmed fish is low or reduced by treatment, the total amount of farmed fish in an area, when combined with the high reproductive capacity of individual female lice and the planktonic dispersal of copepodite stages can result in the spreading of lice outbreaks between farms and cause epidemics on wild fish (Skaala *et al.,* 2014; Skarðhamar *et al.,* 2018).

Fish infected by salmon lice is exposed to an increased likelihood of bacterial and viral infections and, if many lice are present, problems with osmotic regulation (Pike and Wadsworth, 1999). Out-migrating wild Atlantic salmon (i.e. from freshwater to feeding grounds at sea) can be exposed to high abundances of copepodites emanating from fish farms, particularly in areas with multiple affected farms (Serra-Llinares *et al.,* 2014; Halttunen *et al.,* 2018). The duration of the exposure to lice will vary depending on the region; in Norway, exposure lasts from days to weeks depending on the distance from the river to the sea and the migration route chosen by the fish (Forseth *et al.,* 2017). Seat trout (anadromous form of brown trout) and Arctic char reside in the fjords and coastal waters where salmon farms are located, having the potential of being constantly exposed to salmon lice infections while in seawater (Thorstad *et al.,* 2015). Sea trout may return to freshwater to alleviate infestations; as lice fall off their hosts after a period in low salinity water. However, modelling suggests this still represent an overall negative effect on sea trout populations as the fish may experience reduced feeding, growth and fecundity during marine to freshwater transitions (Halttunen *et al.,* 2017).

Population level impacts caused by sea lice will occur if the infection pressure becomes too large and sufficient individuals are harmed. In Norway, negative effects on wild populations have been reported, with a large number of fish farms in a region being identified as the reason(e.g. Finstad *et al.,* 2000; Bjørn *et al.,* 2001; Heuch and Mo, 2001; Heuch *et al.,* 2009; Heuch *et al.,* 2011; Krkosek *et al.,* 2013; Thorstad *et al.,* 2015; Vollset *et al.,* 2016; Bøhn *et al.,* 2020; Serra-Llinares *et al.,* 2020).

Based on data from the period 2012–2020, the IMR risk assessment shows that in the Norwegian Sea ecoregion PZs 8 and 9 the risk associated with mortality in migrating post-smolt salmon as a result of emissions of salmon lice from fish farming is low. In PZs 6 and 7 the risk is considered moderate, while in PZ 5, there is considered to be a high risk of increased mortality. The strength of knowledge is considered to be best where one has good observations that coincide with estimates from models, and worse in areas where the observations are either lacking, not adequate, or where there is no correspondence between observations and models. The strength of knowledge is considered to be good in PZ 9, moderate in PZ 8, and weak in PZs 5–7.

For sea trout and Arctic char, the risk picture differs from that of salmon. In PZs 8 and 9, it is considered that there is moderate risk of negative effects from salmon lice, while in PZs 5–7 there is considered to be a high risk of negative effects on sea trout and arctic char caused by salmon lice infections. The knowledge strength is largely based on available data from ruse and net catches of sea trout and arctic char and compared with the emissions of salmon lice and the distribution of lice in time and space. In all of the PZs (5–9) the strength of knowledge is considered moderate, mainly due to uncertainty in the fish's tolerance limits and behavioural response to salmon lice. The fish's tolerance to lice includes both mortality and premature return to freshwater. Although premature return of lice-infected individuals is a well-documented phenomenon, the direct and indirect consequences of such a behavioural response (in the form of poorer growth, reduced fecundity, etc.) are still poorly known.

### Viral and bacterial pathogens

According to the Norwegian Veterinary Institute viral diseases is a serious problem in fish farming in Norway (Sommerset *et al.,* 2021). The most common pathogenic viruses (salmonid alfa virus (SAV) causing pancreas disease (PD) and infectious salmon anaemia virus (ISAV) causing infectious salmon anemia (ISA) causes 400 to 500 outbreaks of disease along the coast each year. Overall, the situation regarding bacterial diseases of farmed salmonids is relatively favourable and stable. The occurrence of bacterial diseases is low compared to virus, mainly due to the development of efficient vaccines. The most common bacterial infection is winter ulcer, caused by *Moritella viscosa* and in later years outbreaks of Pasteurellosis caused by *Pasteurella* sp. have increased.

Wild fish species may be exposed through a number of different transmission pathways, including water-borne, in matrices such as biofilms and organic wastes, and direct contact either in the containment array or through interactions with escaped fish, and vertical transmission through spawning with infected escaped fish.

For there to be an impact on wild fish from infection outbreaks in farms, a number of things must be true: (1) the wild fish must be susceptible to the infectious agent; (2) the infectious agent must be viable in seawater (for water-borne transmission) or within the biofilm or organic waste, *and* survive in the environmental conditions for a period of time that sufficient for exposure of the wild fish to occur; (3) the concentration of the infectious agent from the farm in the environment must be high enough for infection in wild fish to occur; and finally (4) the wild susceptible fish must be exposed to that concentration for a long enough period of time for infection to occur.

There are several factors that influence whether this series of events will occur. The hydrographic features in the area of the infected farm, which will influence the dilution and dispersal of the pathogen in the water column. The health of wild fish and whether they have previously been exposed to the pathogen (i.e. if immune or immune compromised), will also influence whether or not infection will occur, and what the consequences to the individual wild fish and the wild fish populations in the vicinity of the farm will be.

There have been a number of historical cases where following the introduction of a new pathogen to an area associated with the movement of farmed fish that consequences to wild fish have been demonstrated (e.g. Johnson and Jensen, 1991, 1994). However, for endemic pathogens, the ability to determine a cause–effect relationship between exposure to farmed fish and disease impacts in wild fish is challenging due to the variety of naturally occurring reservoirs, the vastly different environmental conditions for wild fish compared to farmed fish, including on-farm densities.

Risk assessment on change in occurrence of pathogens in wild salmon has been conducted for the two most common pathogenic viruses causing infectious salmon anaemia (ISA) and pancreas disease (PD). In the whole Norwegian Sea ecoregion outbreaks of ISA are few and the risk of change in disease outbreaks is considered low. Over time, there has been relatively good control of ISA in Norway, thanks to intensive work in the industry and strict management measures. Nevertheless, there has recently been an increasing trend in the number of ISA cases which means that the situation can change quickly in all PZs.

For PD, we see that in PZs 5–6 (within endemic zone), where PD occurs very frequently, there is a moderate risk that there will be a change in the incidence of disease in wild salmon as a result of the spread of SAV from salmon farming. In PZ 7, where PD occurs in smaller numbers, risk is considered low and in production 8–9 (outside endemic zone), there is little or no incidence of PD and as long as there are few or no outbreaks of PD in these areas, the risk of change in disease in wild salmon will be very low. Outside the endemic zone, the situation may change significantly in future if the measures to prevent spread are not good enough.

The strength of knowledge is considered to be weak for both viruses in all PZs. We see that there are discrepancies between what we expect to find from infection in wild salmon stocks and what our monitoring data show. This may indicate that there are underlying mechanisms we do not have control over that can cause surprises, for example in the form of the spread of infection in some rivers that we are unable to identify with our monitoring.

## Genetic impacts on wild salmon stocks caused by escaped farmed salmon

Breeding programs, aiming to optimize fish to a life in captivity while selecting for production related traits, have been initiated for some of the most important fish species in aquaculture (Teletchea and Fontaine, 2014). Due to directional selection, in addition to inadvertent selection, farmed fish may deviate from its wild conspecifics in a broad range of traits (Glover *et al.*, 2017). This has raised serious concerns related to farmed fish escaping into the natural environment. These worries are related to negative effects escaped individuals may pose on the local populations through interbreeding with wild conspecifics and thus compromising their genetic integrity. In Norway, most focus on negative effects from escapees comes from intensive farming of salmonids, mainly Atlantic salmon.

Each year, large numbers of domesticated salmon escape from fish farms and into the wild environment. In Norway, number of escapees has ranged from 10 000 to 900 000, with an average of approximately 300 000 escapees per year (2001–2019; source: Directorate of Fisheries). Farmed salmon kept in floating net pens in the sea can escape into the natural environment both acutely, e.g. through large escape events, and chronically, e.g. through continuous leakage from different parts of the production-cycle. Reasons for escape may vary. In Norway most escape incidents are caused by handling operations (delousing, moving of fish or cleaning practices) or failure of technical equipment (strong wind and wave exposure) (Jensen *et al.*, 2010; Føre and Thorvaldsen, 2020). Rifts in the net may occur during handling operations and can be difficult to discover, causing continuous leakage of farmed fish over a longer period. Floating debris, like logs, and accidents with marine traffic also poses a potentially risk for escapes.

Most escapees just disappear, never to be seen again, but some survive and enter rivers where they can interact with the local population. In Norway, Atlantic salmon is a widespread species with a high degree of local adaptation, where relatively closely related populations may differ significantly in phenotypic traits as well as life history traits (Taylor, 1991; García de Leániz *et al.*, 2007; Fraser *et al.*, 2011). Farmed salmon has been through an intense breeding program for ~15 generations (Gjedrem *et al.*, 1991; Gjøen and Bentsen, 1997; Gjedrem, 2010) and have gone through a domestication process with a reduction in genetic variation as a result (Skaala *et al.*, 2004; Karlsson *et al.*, 2010). Consequently, farmed Atlantic salmon deviate from its wild conspecific's in a broad range of fitness-related traits. These include growth (Fleming and Einum, 1997; Glover *et al.*, 2009; Solberg *et al.*, 2013b; Harvey *et al.*, 2016a; Harvey *et al.*, 2016b; Perry *et al.*, 2020), external morphology (Fleming and Einum, 1997; Jørgensen *et al.*, 2018; Perry *et al.*, 2019), aggression (Einum and Fleming, 1997), stress tolerance (Solberg *et al.*, 2013), anti-predator response (Houde *et al.*, 2010; Debes and Hutchings, 2014), predation susceptibility (Solberg *et al.*, 2020), and ultimately survival in the wild (McGinnity *et al.*, 1997; Fleming *et al.*, 2000; McGinnity *et al.*, 2003; Skaala *et al.*, 2012; Skaala *et al.*, 2019). Traits that are beneficial for a life in the domesticated environment may be maladaptive for a life in the wild, and introgression of domesticated salmon may therefore reduce the viability of the wild populations.

Farmed salmon has been monitored in Norwegian rivers since the late 1980's, and in 2019 approximately 200 rivers were monitored through the national monitoring programme. These rivers are geographically widely distributed through the country, and reports from the programme demonstrates that escapees are present in all regions, even those with no active salmon farming (Diserud *et al.*, 2019a; Glover *et al.*, 2019). While the proportion of escaped farmed salmon in Norwegian rivers has varied between years, there has been a declining trend in the records of the past few years.

The risk assessment shows that in the Norwegian Sea ecoregion PZs 5 and 6 are considered to have a moderate risk of further genetic change while PZs 7–9 are considered to have a high risk of further genetic change as a result of escaped farmed salmon. The strength of knowledge is considered moderate in all PZs, mainly due to the lack of data on the actual number of escaped farmed salmon at the breeding grounds and also that there are salmon rivers with no monitoring or removal of escaped fish.

## Effluents

### Dissolved and particulate organic effluents

Although greater than 90% of the fish feed is ingested, and a large proportion of the proteins and lipids are digested, there is a still a significant portion of the feed that is excreted as faeces in addition to bacterial biomass and waste products of metabolism.

Dissolved effluent from fish farms rapidly mixes into the water column and has the potential to cause several environmental problems. Elevated levels of nutrients, especially ammonium nitrogen ($NH_4$+-N) can theoretically lead to water column eutrophication (e.g. Pridmore and Rutherford, 1992) and phytoplankton blooms (including harmful and non-harmful algae species). The effect of dissolved effluent is site-specific due to hydrodynamics (waves and currents), streams and the nutritional status of the water body and the receiving water body. Norwegian waters for example are largely oligotrophic (nutrient-poor), and the addition of nutrients is generally not perceived to be a negative issue thus the risk of effects is considered low. In the Norwegian Sea ecoregion fish farms are mainly located in moderate to high wave exposed areas with high currents that spread and dissolve the nutrients quickly. Although the risk is considered low, the knowledge base is considered moderate to poor due to the lack of coastal water monitoring in this ecoregion.

Particulate waste from sea-based fish farms enters the marine environment in two primary forms: waste feed (uneaten pellets) and fish faeces. The majority of the particulate waste (and vast majority by mass) is deposited within a few hundred meters of the fish cages and is most concentrated directly beneath the cages unless the fish cages are situated in a location with strong hydrodynamics. Finer faeces particles are dispersed more widely and can be traced as far as 1 – 2 km from the farm (Woodcock *et al.*, 2018; Keeley *et al.*, 2019). Biodeposits from fish farms can cause severe benthic organic enrichment and contamination which manifests as pronounced biological and geochemical changes to soft-sediment habitats (Brooks *et al.*, 2002; Brooks and Mahnken, 2003; Hargrave *et al.*, 2008). Extremely enriched conditions can result corroborated by anaerobic and azoic sediments directly beneath the cages. Benthic effects grade progressively with distance away from the farm achieving natural conditions within 200–1000 m away (Kutti *et al.*, 2007; Keeley *et al.*, 2013, 2019; Broch *et al.*, 2017).

Elevated depositional loads of organic waste can also affect other components of the marine ecosystem, although many of these interactions remain less well documented. Epibiota colonizing hard substrata can be impacted, some negatively (e.g. sponges, Sutherland *et al.*, 2018) and some may proliferate in response to organic waste (e.g. brittlestars, Keeley *et al.*, 2020). Effects on most of the larger epibiota or reef-dwelling species are generally poorly documented. Negative effects to sensitive and / or valuable species or habitats are a related issue that occasionally warrants specific attention, for example maerl beds, corals and seagrass habitats (Hall-Spencer *et al.*, 2006; Sanz-Lazaro *et al.*, 2011), corals (Bongiorni *et al.*, 2003) and seagrass habitats (Cancemi *et al.*, 2003).

The risk of effects due to particulate organic waste on soft bottom locations is considered low in all PZs of the Norwegian Sea ecoregion based on results of the monitoring program. The environmental status is categorized as very good or good for about 95% of the fish farms and none were categorized as very bad in 2020 in the ecoregion. Risk of effects of particulate waste on hard bottom substrata is considered as moderate due to the lack of appropriate monitoring methodology.

## Environmental pollutants

There are a number of contaminants that are released into the environment from fish farms. Fish feed can contain various environmental toxins that come from the feed ingredients and these can be added to the environment both through feed waste and through the fish waste (faeces). The substances that are dispersed to the environment from fish feed and faeces come from the feed ingredients. Approximately 70% of the ingredients are currently plant-based and 30% are based on marine raw materials. The raw materials used for feed production may contain halogenated organic compounds such as PCBs, dioxins, furans, chlorinated pesticides, brominated flame retardants and heavy metal compounds such as mercury (Hg), arsenic (As) and cadmium (Cd), copper (Cu) and zinc (Zn). Other substances are added to the feed in small amounts and are necessary for the fish to ensure good fish health and growth. This also includes Cu and Zn which therefore also fall into the category of minerals when they are added to the feed. However, the amounts of Cu from feed waste and faeces are far smaller than those from copper as an impregnating agent, which is the substance with the greatest concern.

The use of copper for impregnating net pens is considered to be the largest source of environmental pollutants from fish farming in Norway (Skarbøvik *et al.*, 2017). In 2019, 1698 tonnes of copper was used as antifouling treatments of net pens for fish farming (source: Produktregisteret). EU has calculated that about 80% of the antifouling treatment bleeds out during the time between coatings, giving an estimate of 1358 tonnes copper released to the environment. Especially the use of high-pressure cleaning removes large amounts of copper from the net, mostly as larger particles that sinks to the seabed, but also as dissolved copper ions in the water column. Since copper is very stable in its solid state it will accumulate under the fish farms and the levels of copper increases in the sediment over time. In high concentrations copper is toxic to the marine organisms, both in the water column such as zooplankton and fish larvae and benthic organisms living in and on the sediment (Martin *et al.*, 1981, King and Riddle 2001, Foekema *et al.*, 2015, Hall *et al.*, 1999).

In the Norwegian Sea ecoregion, the moderate increased levels of copper in the sediment in all PZs except PZ 9 should be paid some attention. In PZs 6 and 7 the emission of copper is considered to be high and due to the accumulation of copper in the sediment close to the farms, levels of copper may exceed the environmental limits in these PZs in future.

## Therapeutants

There are a number of therapeutants in use for treating farmed salmon for bacterial diseases (antibacterial agents), intestinal parasites and salmon lice, as well as sedative and anaesthetic agents used for vaccination and transport. Anti-sea lice drugs or therapeutants are by far the most used therapeutants in Norway and are administrated either as a bath treatment or added to the salmon feed (in-feed). Effects of delousing agents on species other than the target species, i.e. non-target species may occur when the therapeutants are released to the environment. The magnitude of the effect is linked with the species sensitivity and the delousing agent’s presence in the environment. The use of anti-sea lice drugs increased in the period 2008-2015, but since 2016 the yearly amount used has steadily decreased mainly due to an increased use of non-medical treatments such as thermic and freshwater bath and mechanical delousing.

Therapeutants given as bath treatment usually takes place in well-boats. After de-lousing the therapeutants are released into to the sea while the boat is in motion, i.e. often some distance from the farm (Parsons *et al.*, 2020). The dispersion and dilution of therapeutants following a bath treatment will vary both between sites and at the same site. This is influenced not only by fluctuating hydrographic conditions such as current, waves, temperature and water stratification at the discharge point but also by the speed of the well boat when released. There are potential effects of the released therapeutants from bath treatment on the pelagic environment, zooplankton, and benthos. Zooplankton are an important part of the foodweb, containing larval stages of many commercial fish and crustacean species. Therapeutants used against sea lice may have detrimental effects on several non-target species, but the effect depends on the agent as well as the species (see e.g. Refseth *et al.,* 2017; Urbina *et al.,* 2019, Parsons *et al.,* 2020, and references therein).

Therapeutants given as in-feed treatments will be bound to organic matter such as uneaten medicated pellets and faeces, which spread to the environment via waste feed and faeces (as described above for particulate organic waste). Bound to organic particles they are relatively stable and residual concentrations can be found in the bottom sediment several months after treatment (SEPA, 1999; Samuelsen *et al.,* 2015). Most of the drugs are found beneath or near the farm (30 to 50 m) where higher levels of these chemicals can be found, though there is mounting evidence that they are being distributed to distances greater than 1000 m (NIVA, 1998; Langford *et al.,* 2011; Samuelsen *et al.,* 2015).

The species most likely to be affected by in-feed agents are those closely associated with the sediment as all agents used have low water solubility and a high potential to be adsorbed onto and bound to suspended particulate material. However, planktonic organisms can be exposed to the agents through water and particulate matter during and immediately after medication but most likely in low concentrations (Samuelsen *et al.,* 2015). The in-feed agents influence the chitin synthesis in the target organism, in this case the sea lice, making it unable to go through moulting and finally causing mortality. When other moulting organisms like shrimp or lobster are exposed to the in-feed drugs, the effects may be the same and laboratory studies have shown that in-feed drugs can cause mortalities in the non-target organisms (Bechmann *et al.,* 2018; Samuelsen *et al.,* 2014, 2020).

Little is known about what the impact is *in situ* from both bath treatments and in-feed medication and more studies are needed to conclude on the ecological effects in the wild.

The risk of using therapeutants is not assessed on a PZ level and no notes are made for any area except PZs 3 and 4 that is south of the Norwegian Sea ecoregion.

## Cleaner fish

Cleaner fish are promoted as an environmentally friendly biological control method for sea-lice, being stocked into salmon net-pens to eat sea-lice attached to the farmed hosts and in the water column. The species being used in such polyculture are lumpfish *Cyclopterus lumpus* and various wrasses (labrids): goldsinny *Ctenolabrus rupestris,* corkwing *Crenilabrus melops*, rock cook *Centrolabrus exoletus,* cuckoo *Labrus mixtus*, and ballan *Labrus bergylta* (Skiftesvik *et al.,* 2014; Riley *et al.,* 2017; Gonzalez and de Boer, 2017). Different size/species of cleaner fish are used at different stages of the salmonid production cycle. Lumpfish are considered more effective at cooler temperatures ( < 6–7°C) at which wrasse may become torpid (Riley *et al.,* 2017; Brooker *et al.,* 2018b; Powell *et al.,* 2018a). Recent analyses suggest that the impact of cleaner fish on sea-lice is variable, and their efficacy may be lower than previously though (Barrett *et al.,* 2020; Gentry *et al.,* 2020). Concern has also been expressed that the effectiveness of cleaner fish may be further reduced by the emergence of transparent unpigmented (rather than brown) sea-lice which are less visible (Soltveit, 2018). Nevertheless, cleaner fish are considered a key sea-lice control, at present and into the foreseeable future (VKM *et al.,* 2019).

The salmonid farming industry has a high demand for cleaner fish due to the high ratios used and replacement. In Norway, all lumpfish used comes from hatchery production while the main part of the wrasses used are wild-caught. The potential environmental interactions associated with the use of cleaner fish are: 1) Fisheries for wild stocks (local overexploitation and bycatch);

2) Escape of non-indigenous genotypes (genetic introgression); and 3) Pathogens (disease transmission) (Grefsrud *et al.,* 2021a).

## Wrasse fishery

In Norway the fishery for live wild wrasse developed quickly from 2011 and the number of wrasse caught went from zero to more than 24 million individuals within a few years. Wrasse are caught from rocky inshore areas using a variety of (static) fishing gear: traditional crab/lobster pots, purpose-built traps, gill/trammel/fykenets, and rod and line, with differences in gear between countries (Skiftesvik *et al.,* 2014; Riley *et al.,* 2017; Gonzalez and de Boer, 2017; VKM *et al.,* 2017). Fishers typically amass stocks in temporary holding systems (e.g. keep/store cages in harbours, onshore tanks) until pick-up and transfer to transportation units for road transport to salmonid farms but may also be delivered directly to farms (VKM *et al.,* 2017; 2019). From 2018 the wrasse fishery became a closed fishery in Norway and a quota was set to 18 million wrasse per year. In the Norwegian Sea ecoregion (wrasse fishery zone 3), the quota is set to 4 million wrasse per year.

The potential effects of fishing pressure on wrasse populations and the inshore ecosystem include:

- localized overexploitation of wrasse populations;
- changes in social and population structure of wrasse as the fishery is sex-, size- and dominance-selective;
- reduced wrasse egg survival (and recruitment) if nest-guarding males are removed;
- changed community structure, as wrasse are considered a keystone grazing and prey species;
- increased sea-lice loads on wild fish, if wrasse perform a cleaning function in the wild;
- reductions in populations of bycatch species.

## Genetic introgression

Recovery of stocked cleaner fish from net-pens after deployment is low. The loss is largely attributed to mortality, but escape is likely to contribute. Cleaner fish may escape by passing through the mesh (small fish only) or through areas of net damage. Survivors at the end of a production cycle may also have been intentionally released although this is against Norwegian regulations. Furthermore, some of the wrasse species used are broadcast spawners, so escape of non-indigenous genotypes could occur if spawning occurs within net-pens. Escaped and released fish may differ genetically to the local population. In Norway, to meet the demand in mid- and northerly regions where wild wrasse catches are low, fish are translocated from southern Norway (Skagerrak coast) and Sweden (Skiftesvik *et al.,* 2014; Gonzalez and de Boer, 2017; VKM *et al.,* 2019 Faust *et al.,* 2018). In mid-Norway, hybridization of escapee with local populations has been demonstrated for corkwing wrasse (Faust *et al.,* 2018) and is suspected for goldsinny wrasse (Jansson *et al.,* 2017). Such mixing of genotypes between isolated populations can potentially result in loss of local adaptation and introgression as discussed for salmon. However, whether escapes do have a genetic impact on local populations will depend upon the number of escapees relative to the wild population size, their survival and reproductive success, and the genetic difference between local and introduced fish (Whittaker *et al.,* 2018).

## Disease transmission

Cleaner fish are susceptible to a variety of viral, bacterial, fungal and parasitic diseases and can also carry pathogens, without displaying signs of infection; e.g. notifiable viruses have been detected in farmed lumpfish (Korsnes *et al.,* 2017; VKM *et al.,* 2017; Brooker *et al.,* 2018b; Powell *et al.,* 2018). Cleaner fish in farms may therefore act as a reservoir of infection for endemic pathogens to wild fish. Deployment of cleaner fish, of either farmed or translocated wild origins, may also introduce novel pathogens, or new strains of pathogen, that then affect wild conspecifics and other species (Skiftesvik *et al.,* 2014; Korsnes *et al.,* 2017; VKM *et al.,* 2017; Faust *et al.,* 2018). Furthermore, polyculture of salmonids with lumpfish and various wrasse species under intensive farming conditions has the potential for interspecies transmission and novel pathogen emergence (Murray, 2016; VKM *et al.,* 2017; Brooker *et al.,* 2018; Powell *et al.,* 2018).

The IMR risk assessment shows that in the Norwegian Sea ecoregion PZs 5–8 (PZ 9 is not included in the risk assessment since wild-caught wrasse is not used for delousing north of PZ 8) there is a high risk that there will be environmental effects as a result of using wild-caught wrasse for de-lousing. If current practice of using wild-caught wrasse is maintained, it must be expected that undesirable events such as the spread of infection and genetic alteration will occur. In addition, undesirable effects must be expected as a result of the actual fishing for wrasse. Overall, the strength of knowledge is considered moderate for all PZs, as there is still a need for knowledge of genetic change in wild stocks of wrasse caused by escaped wrasse from salmon farming, effects of fishing wrasse in the area and in general about the spread of infection and introduction of new pathogens as a result of transport and movement of fish.

## Wild fish interactions

No risk assessment has yet been conducted on wild fish interactions, thus specific information about the Norwegian Sea ecoregion is not available. The following paragraphs various interactions are described assuming to be driven by the same mechanisms independent of ecoregion.

### Migrating behaviour

Internationally, there is relatively little knowledge of the avoidance of wild fish from salmon farms, or on possible impact on the migration pattern (Callier *et al.,* 2018; Barett *et al.,* 2019), and there has been little or no new research on this in the last 10–15 the years. In Norway, however, fishers have long claimed that cod on spawning migration avoids spawning grounds in farming intensive fjords. Fishers' ecological knowledge has been studied through interview surveys and social science methods (Maurstad *et al.,* 2007). The conclusion is that fishers have made reliable observations of cod behaviour in aquaculture-intensive areas, both avoidance and attraction, but that scientific studies are needed to conclude with greater certainty, as well as suggest the mechanisms behind any changes (Maurstad *et al.,* 2007).

Although some studies have been conducted, both in laboratory and field the results are inconclusive and not sufficient to show whether intensive farming activity (primarily salmon farming, but it can also apply to other fish farming, live storage and catch-based aquaculture) actually leads to wild cod avoiding historically spawning grounds (Sæther *et al.,* 2007; Bjørn 2007; Bjørn *et al.,* 2009).

### Fish Aggregating Device

Open net pens in the coastal zone may attract fish and other wildlife to fish farms for several reasons and result in large aggregations around the salmon farms. The physical structures, such as moorings and cages, provide shelter for small fish and habitat for various organisms. Spillover feed and organic waste attract wild fish which again can attract larger predatory fish and in addition artificial lighting can attract invertebrates such as krill *Thysanoessa inermis* which is an important prey item for Atlantic cod. The attraction of wild fish for habitat and feeding makes the salmon farms function as Fish Aggregation Devices (FADs) (Callier *et al.,* 2018; Sanchez-Jerez *et al.,* 2011). Especially saithe, *Pollachius virens*, gathers close around the net pens, but also species such as mackerel *Scomber scombrus*, Atlantic cod and haddock *Melanogrammus aeglefinus* were found to aggregate under Norwegian fish farms (Dempster *et al.,* 2009, 2010). The changes in species diversity and the amount of fish in connection with fish farms can have consequences for the ecosystem, which can ultimately lead to negative effects on nutrient composition and productivity in the system (Gamfeldt *et al.*, 2015). A meta-analysis of environmental impacts from aquaculture was carried out by Barrett *et al.*, (2019), which found an increased abundance of wildlife around aquaculture facilities, mainly of fish. The authors also found that wild fish associated with farms were 1.7 times heavier than fish not associated with farms, as well as a dietary change to either pellets or other prey.

It has been shown that wild fish can stay very close to fish farms for relatively long periods, and that they migrate quickly and often between several farms, as well as to other nearby habitats such as spawning grounds or historical fishing grounds (Uglem *et al.*, 2008, 2009; Dempster *et al.*, 2010; Otterå and Skilbrei 2012; Sanchez-Jerez *et al.*, 2011). In Norway, this has been shown for both cod and saithe (Uglem *et al.*, 2008, 2009; Otterå and Skilbrei 2012).

### Physiological effects of spillover feed

Spillover feed from fish farms can have a physiological effect on the wild fish around. The diet for wild Atlantic cod ranges from natural prey with a high content of marine omega-3 fatty acids to food with a high content of omega-6 fatty acids that originate from terrestrial feed products (Fernandez- Palacios *et al.*, 2011; Olsen *et al.*, 2015). Commercial fish feed used in Norwegian salmon farming contains omega-6 fatty acids from soybean oil, sunflower oil or rapeseed oil, and thus reduces the omega-3 concentration both in the feed and in the salmon (Aas *et al.*, 2019). Changes in the omega-3 / omega-6 ratio can lead to changes in fecundity and thus lead to lower larval survival (Izquierdo *et al.*, 2001). The fatty acid composition of female fish is correlated with the fatty acid composition of the eggs (Pickova *et al.*, 1997; Røjbek *et al.*, 2014), but the fatty acids EPA; ARA and DHA also have an impact on reproductive physiology, egg and sperm quality, hatching success and larval survival (Norberg *et al.*, 2017; Rahman *et al.*, 2014; Salze *et al.*, 2005; Zakeri *et al.*, 2011 ).

Cod that graze on pellets rich in terrestrial fatty acids will therefore potentially be able to produce eggs with a lower or unbalanced content of specific nutrients that are important for the offspring's quality and survival. In an experimental study, spawning and quality of offspring for cod in an area with intensive salmon farming were compared with cod caught on sites with less farming activity (Barrett *et al.*, 2018). Differences were found in egg production and egg size, but not in larval parameters. Although terrestrial fatty acids were found in the ovaries of individual fish, there were no significant differences between the groups. To increase the strength of knowledge of effects of spillover feed on reproduction, more studies are needed.

## Animal welfare

Hundreds of millions of farmed fish currently swims around in Norwegian fish farms, far more than the number of any other production animal in Norway. Norwegian production of farmed fish is dominated by Atlantic salmon, but millions of rainbow trout, char, halibut, cod and cleaner fish (lumpfish and wrasse) are also farmed. The number of salmon released into the sea has more than doubled since the turn of the millennium, from less than 150 million per year to over 350 million in 2019. These are individuals who according to the Animal Welfare Act are entitled to be kept in an environment that provides good welfare based on species and individual needs, and the possibility of stimulating activity, movement, rest and other natural behaviours. The fish farmers must also ensure that the feed is of good quality and covers the fish's needs, that the farmed fish is protected against injury, disease and other dangers. The farmed fish must be robust enough and have the prerequisites to withstand the farming conditions, and they must not be exposed to unnecessary stress and strain. Indicators of poor welfare are disease, parasites, wounds and injuries, poor growth and weight loss, and deviant behaviour (Noble *et al.*, 2020). As mortality can be a consequence of poor animal welfare, it is regarded as an important indicator to determine the condition and status of the fish farming industry. In the period 2018–2020, average monthly mortality of farmed salmon in sea cages varied between 0.6 to 1.7 in PZs 5–9 (Grefsrud *et al.,* 2021b). There are no exact overview of mortality in hatcheries, but based on existing numbers and estimates mortality rates are higher compared to salmon in sea cages. According to the Norwegian Food Safety Authority's cleaner fish campaign mortality rates in cleaner fish (wrasse and lumpfish) during a production cycle is 42% (Stien *et al.,* 2020). However, the authors points out that the actual mortality most likely is significantly higher.

In hatcheries, the risk of poor welfare for salmon is considered moderate. The strength of knowledge is considered moderate, as there is too little valid data available from the industry to be able to follow fish groups over time. The assessment further shows that in the Norwegian Sea ecoregion the risk of poor welfare of salmon in cages in the sea is moderate for PZs 6–9, while it is considered high for PZ 5. The challenges in the north are primarily related to low temperatures and bacterial wound infections, while Western Norway has major challenges with PD and injuries in connection with frequent de-lousing operations. It must be emphasized that within the areas there is great variation between localities and fish farming companies, so these conclusions do not necessarily apply to all fish farms within a region. The strength of knowledge for PZ 5 is considered good, based on reliable data that shows a high incidence of pancreas disease (PD), high frequency of de-lousing operations and relatively high mortality compared to PZ 6–9 where strength of knowledge is considered moderate due to less data available.

The open net pens are constructed, and the sites have been chosen, to be optimal for salmon farming and are not well adjusted for the cleaner fish used. The risk of poor welfare in lumpfish and wrasse is considered high in all PZs including those in the Norwegian Sea ecoregion. Temperatures, strong water flow and especially disease, parasites and stress and damage, mainly due to de-lousing operations, are considered to be far from the desired condition. Strength of knowledge is considered good based on what we know about diseases and parasites and that there is a high incidence of stress and injuries in cleaner fish. In addition, based on the knowledge of natural behaviour and life cycle in the wild, we know that the cleaner fish used is poorly adapted to a life in salmon cages. The clear results from the Norwegian Food Safety Authority's cleaner fish campaign where the mortality of both lumpfish and wrasse is high, also supports the conclusion (Stien *et al.,* 2020).

## Seaweed and blue mussel farming

There are some locations producing macroalgae in the Norwegian Sea ecoregion (PZs 5, 6, 8 and 9) and in PZs 6–8 there is longline production of blue mussels in a few areas. Seaweed cultivation is considered to have less negative environmental impacts (Hasselström, 2018; Visch, 2020; Norderhaug *et al.,* 2021) compared to finfish farming while longline mussel production may have an impact on benthic communities (McKinnon, 2003; Solomon and Ahmed, 2016), local hydrodynamics (McKindsey, 2011; McKindsey *et al.,* 2011; Cranford *et al.,* 2012, Forrest and Hopkins, 2017), phytoplankton abundance (Grant *et al.,* 2008; Petersen *et al.,* 2008; Strohmeier *et al.,* 2008; Cranford *et al.,* 2011), zooplankton abundance (Zeldis *et al.,* 2004; Lehane and Davenport, 2006; Maar *et al.,* 2008), pathogen transmission (Brenner *et al.,* 2014) and sensitive habitats (Peña and Bárbara, 2008b; Peña, 2010). No risk assessments have been conducted on seaweed or mussel production in the Norwegian Sea ecoregion.

## Sea mammals

It does not seem that conflicts between marine mammals and aquaculture is a major problem in Norway. However, there have been a couple of episodes where minke whales (*Balaenoptera acutorostrata*) and humpback whales (*Megaptera novaeangliae*) have become entangled in the anchors of the farms. What is probably more common is that coastal seals (harbour seals *Phoca vitulina*, and otters *Lutra lutra*) graze near fish farms with the possibility of increased stress levels in farmed fish. Studies of this kind of impact has not yet been conducted in Norway. The worst-case scenario of aquaculture-seal interactions is damage to fish pens with subsequent mass escape of farmed fish (Bjørge *et al.,* 2001). Until 2020, it was allowed to shoot seals at fish farms. Such killings were to be reported to the Norwegian Directorate of Fisheries, but very few if any killings have been reported. In the WGMME annual report entanglement of marine mammals, acoustic impact from Acoustic Deterrent Devices and vessel-based disturbance and collisions are discussed. So far, none of these issues seems to be a big problem in the Norwegian Sea ecoregion.

## Seabirds

Environmental impacts of aquaculture activities on seabirds may include entanglement by the farm itself or by marine debris from the production, physiological impact through seabirds foraging on fish feed or switching from other food sources to the species cultured (e.g. mussels, oysters) and disturbance from the farm activity (noise, collision with farm or vessels, lighting) are also identified as possible hazards to seabird populations (Surman and Dunlop, 2015). Mitigation efforts such as covering the net pens with bird mesh, reduce the use of lighting, video monitoring (both above and below the water surface) to detect entangled birds, return of waste to mainland for further deposition and reduce speed of operating vessels may reduce the impact on seabirds (Surman and Dunlop, 2015). No risk assessment on environmental impact of aquaculture on seabirds have been conducted in the Norwegian Sea ecoregion.

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# Annex 5: Report of the ICES Aquaculture Stakeholder Survey

## Executive summary

ICES works to advance our understanding of marine ecosystems and to share scientific understanding of marine ecosystems and the services they provide. This knowledge is used to generate state-of-the-art advice that meets conservation, management, and sustainability goals.

ICES currently publishes advisory products, "overviews" on the state of the ecosystem and fisheries. ICES is working to develop a new advice "overview" on aquaculture. In an effort to prioritize the content of the ICES aquaculture overviews for stakeholders, the ICES Aquaculture Overview Operational Group developed a short stakeholder survey and shared it with national level stakeholder groups identified by ICES Member Countries. The survey asked about the type of work the respondents do and where they work, (regulatory/policy, science, industry, NGO), their aquaculture advisory needs, and their desired format for an advisory product. The process of soliciting respondents, the content of the survey, and the results of the survey are summarized in this report.

## Introduction

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. There are seven working groups in ICES with their activities being coordinated by the Aquaculture Steering Group.

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.'

ICES seeks to develop aquaculture overviews that are highly relevant to all stakeholders, will inform decision-makers and are based on the best available science and information. The process of establishing ICES aquaculture overviews was initiated in 2019, with i) forming a core group consisting of representatives from ACOM leadership, SCICOM and the Secretariat, and ii) agreeing on the directions and procedure of further work of the core group at its first meeting at ASC 2019. The key activities performed included: i) arranging regular web conference meetings of the core group and establishing a SharePoint Site for the planning process of aquaculture overviews; ii) establishing a network of national experts to support the core group in the production of the series of Aquaculture Overviews, based on invited nominations from ACOM and SCICOM members; iii) establishing the database on national and international stakeholders, based on information provided by national experts; iv) performing a stakeholder survey to solicit feedback on the potential contents of aquaculture overviews, and v) consultations in ACOM and SCICOM in March 2020 to obtain feedback on the work performed and advice for future plans.

### Stakeholder survey objectives

In an effort to prioritize the content of the ICES aquaculture overviews for stakeholders, the ICES Aquaculture Overview Operational Group developed a short stakeholder survey and shared it with national level stakeholder groups identified by ICES Member Countries. The survey asked about the type of work the respondents do (regulatory/policy, science, industry, NGOs), where they work, their aquaculture advisory needs, and their desired format for an advisory product. The process of soliciting respondents, the content of the survey, and the results of the survey are summarized in this report.

The objectives of Aquaculture Overviews 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.

## Methods

ACOM and SCICOM were asked (via the ICES committee forums) to nominate national-level aquaculture experts to contribute to the development of the ICES Aquaculture Overviews. ICES asked these national nominees for national-level aquaculture stakeholder lists. Fourteen members of ACOM and SCICOM made nominations, including Canada, Estonia, Finland, France, Germany, Ireland, Latvia, Norway, Poland, Portugal, Spain, United Kingdom, and the United States. The Faroe Islands and Greenland and organizations that ICES works with, like UN FAO were approached. The nominees were then approached with the survey.

The Aquaculture Overview Operational Group developed the survey questionnaire (Annex 3) and cover letter (Annex 2) to be distributed to the identified national-level aquaculture stakeholders. The survey was initially developed as a paper/e-mail format, but it was moved to an online platform to be more efficient and to comply with the EU General Data Protection Act. An introductory e-mail, including the survey link, was sent to each stakeholder submitted to ICES with a reference to how we received their contact information (Annex 2 and 3).

ICES offered to translate the survey into French, Spanish and Portuguese in an effort to increase participation by stakeholders in these countries. No translations were made available as national nominees did not respond.

Survey responses were compiled and coded by type of respondent/organization: regulatory, science, industry, non-governmental organization (NGO). The latter type (NGO) contains responses of stakeholders working for NGOs who identify as working on a combination of policy, management and science activities.

In late 2019 it was agreed that ICES would produce Aquaculture Overviews by ICES ecoregion and the information provided in these overviews would be informed by a survey of national-level aquaculture stakeholders in ICES Member Countries.

## Results

Ten ICES Member Countries and at least one affiliated organization responded to the stakeholder survey (Table 1). In total, forty-four completed surveys were submitted and the results are summarized here. Further detail is not provided due to data protection provisions.

Responses were received from throughout the ICES area, with 59% of survey responses coming from individuals working in the Northeast Atlantic and 41% from individuals working in the Northwest Atlantic.

**Table 1. Summary of information on ICES national nominees on aquaculture, stakeholder lists, and survey responses.**

| ICES member country or associated organization | National nominees | Stakeholder lists provided | Response(s) received |
|---|---|---|---|
| Belgium | | | |
| Canada | X | X | X |
| Denmark | | | X |
| Estonia | X | | |
| Faroe Islands | X | * | |
| Finland | X | X | X |
| France | X | * | |
| Germany | X | X | X |
| Greenland | X | ** | |
| Iceland | | | |
| Ireland | X | X | X |
| Latvia | X | | |
| Lithuania | | | |
| Netherlands | | | |
| Norway | X | X | X |
| Poland | X | X | X |
| Portugal | X | * | |
| Russian Federation | | | |
| Spain | X | * | X |
| Sweden | | | |
| United Kingdom | X | X | X |
| United States | X | X | X |
| IOE | | | unknown |
| UN FAO | | | X |

*** National nominee asked to reach out directly to stakeholders with survey.**

**** Greenland has no aquaculture activities at present.**

When asked which management objectives and issues required advice, the respondent groups were able to choose as many topics as they wished as well as a free text field, "other" (Figure 2). Overall, 100% of NGO respondents stated that that "carrying capacity and efficiency of aquaculture systems" and "environmental impacts and mitigation options"

Survey respondents were grouped by type of organization they work for and the type of work that they do. Stakeholder or respondent "types", regulatory/policy, science, industry, and NGOs were each equally represented with 34% and 16% of overall responses (Figure 1).

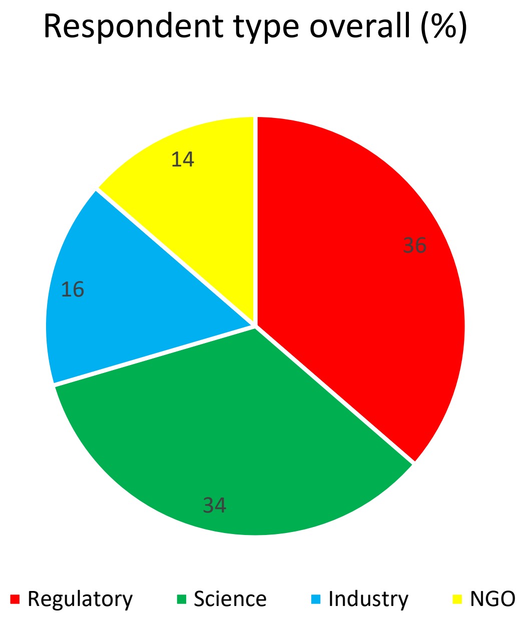

**Figure 1. Survey respondent types (percentage).**

Respondents were asked to identify management objectives and issues that require advice (Figure 2) and to indicate which topics should be included in the Aquaculture Overview (Figure 3). Respondents could select as many options as they wished and they could enter additional issues in a free field "other".

**Figure 2. Management issues that require advice (a) overall (all respondents grouped) and (b) by respondent group.**

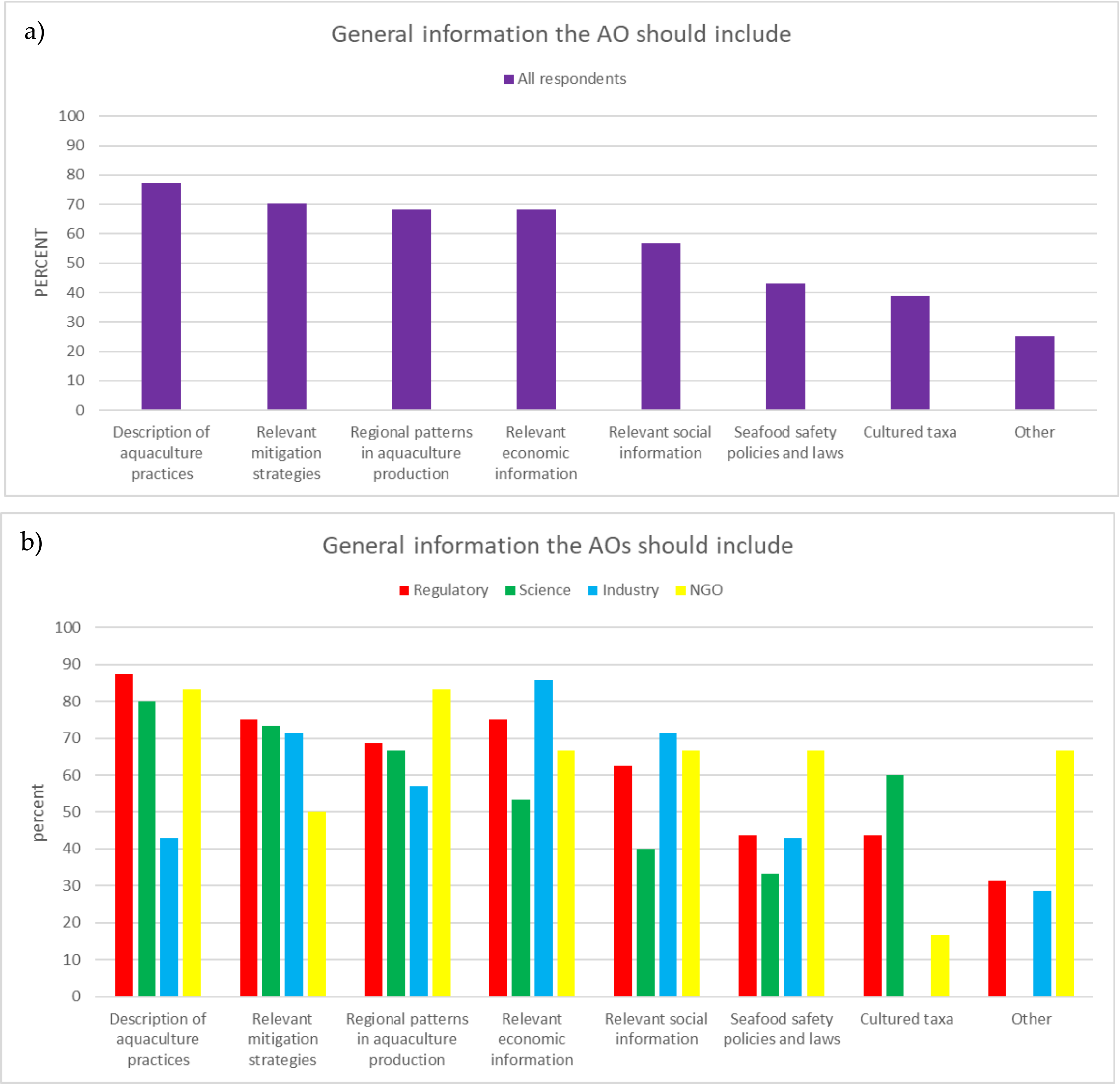

**Figure 3. Topics that should be included in the aquaculture overviews (AO) (a) overall (all respondents grouped) and (b) by respondent group.**

Survey questions 7 and 8 (see Annex 3) were answered by the majority of respondents (42 and 40 of 44 respondents, respectively).

- Survey question 7: what areas of information are currently lacking that could help support management or regulatory decisions in your field?
- Survey question 8: briefly explain how you use science to information your decisions with respect to aquaculture.

These responses did not easily fit into clear categories so word clouds were used The size of a word shows how important, that is how frequently it appears in a text.

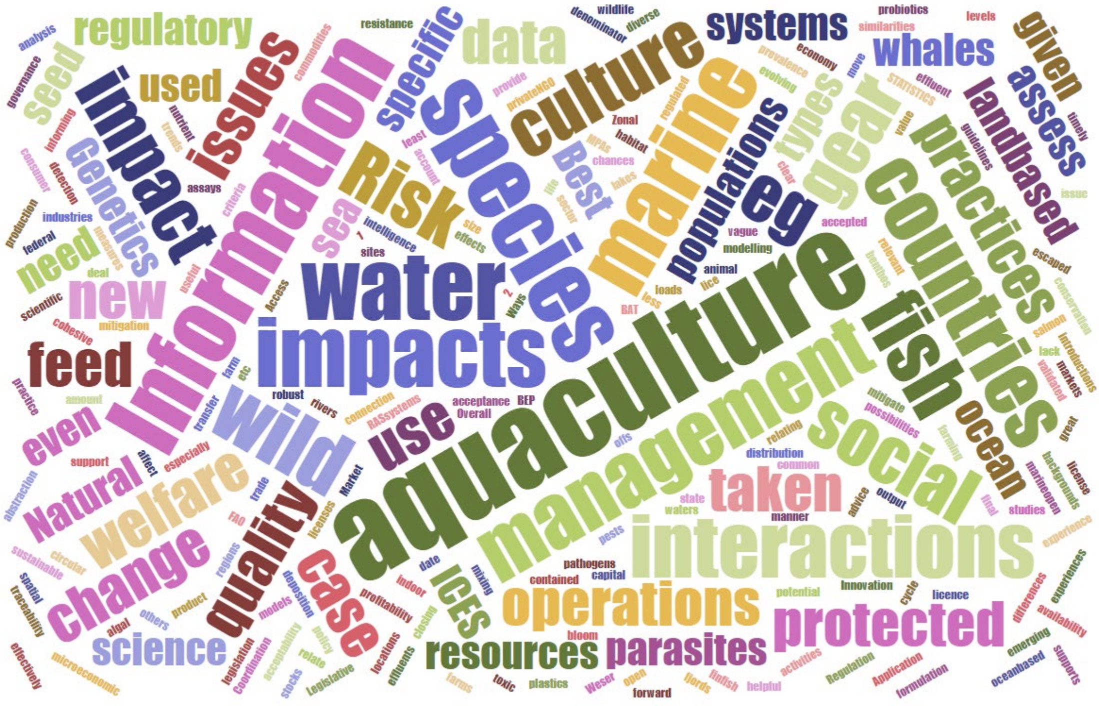

Figure 4. Word cloud from answers from Question 7; what areas of information are currently lacking that could help support management or regulatory decisions in your field? (42/44 respondents answered).

Figure 5. Word cloud from answers from Question 8; briefly explain how you use science to information your decisions with respect to aquaculture. (40/44 respondents answered).

The survey also asked about the preferred format for the Aquaculture Overviews. The majority of respondents (63%) preferred an online interactive format or webpage over a traditional document or pdf.

## Discussion

ICES is developing a new advice "overview" on aquaculture. In an effort to prioritize the content of the ICES aquaculture overviews for stakeholders, the ICES Aquaculture Overview Operational Group developed a short stakeholder survey and shared it with national level stakeholder groups identified by ICES Member Countries.

This stakeholder survey tool is simple in nature and should not be overinterpreted. It was very useful in that it supported the work of the Operational Group with real-world, practical information to create an advisory product that is fit for purpose and responsive to the needs of the ICES network.

The survey data are not sufficient for a regionally specific analysis, but responses provide inputs for what to consider in planning of the AO. Southern European responses are missing and it would be useful to gather information from these member states going forward.

It would also be useful to solicit further feedback from key resources in the region such as the Aquaculture Advisory Council, the Federation of European Aquaculture Producers, the DGMARE aquaculture stakeholder survey.

Of particular note in the survey responses is that among the four different stakeholder types, industry, NGO, science and regulators, there was high interest in social and economic information in Aquaculture Overviews and the impacts of climate change.

The survey responses informed discussions in the Aquaculture Operational Group on the proposed contents of the Aquaculture Overview. This is a draft proposal. ACOM will make the final decision on the subject matter included in and scientific content of the overview.

# List of participants in the Aquaculture Overviews Operational Group (Annex 1)

| Name | Institute | Country (of institute) |
|---|---|---|
| Anne Cooper | International Council for the Exploration of the Sea (ICES) | Denmark |
| Henn Ojaveer | International Council for the Exploration of the Sea (ICES) | Estonia |
| Janet Whaley | NOAA Fisheries | USA |
| Malene Eilersen | International Council for the Exploration of the Sea (ICES) | Denmark |
| Michael Rust | NOAA Fisheries | USA |
| Seth Theuerkauf | NOAA Fisheries | USA |
| Ryan Carnegie | Virginia Institute of Marine Science | USA |
| Terje Svåsaand | Institute of Marine Research (IMR) | Norway |

# Survey cover letter developed and distributed by the Aquaculture Overviews Operational Group (Annex 2)

ICES
CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Stakeholder engagement to design ICES Aquaculture overviews

My name is Anne Cooper and I work on aquaculture and fisheries advice at the International Council for the Exploration of the Sea (ICES). You are receiving this message on the ICES Aquaculture Overviews because the ICES national aquaculture nominee for **Country, Name** identified you or your organization as an important national-level stakeholder on sustainable aquaculture.

The International Council for the Exploration of the Sea (ICES) is an intergovernmental marine science organization, meeting societal needs for impartial evidence on the state and sustainable use of our seas and oceans. Our goal is 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 new ICES Strategic Plan states that, *'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*'. While fisheries and ecosystem overviews are already available for several ecoregions, ICES is now designing the scope, content and layout of the aquaculture overviews and we are actively soliciting input from key members of our community in order to develop the best products to meet the needs of stakeholders.

ICES seeks to develop aquaculture overviews that are highly relevant to all stakeholders, will inform decision-makers, and are based on the best available science and information. To better achieve these objectives, ICES asks for your input[2] on the following:

1. What management objectives/issues require advice?
2. What information should the overviews contain?
3. How should the overviews be presented and communicated?

Please take 5–10 minutes to share your thoughts and ideas by completing the ICES survey on stakeholder engagement on the Aquaculture Overviews https://icessurveys.typeform.com/to/ko7Qyw. . We would appreciate it if you could complete the survey by **DATE**.

If you would like further information on the survey, the Aquaculture Overviews, ICES, etc., please do not hesitate to e-mail or telephone me. My contact details are below.

Many thanks,

Anne M. Cooper, Ph.D.
ICES Professional Officer
anne.cooper@ices.dk

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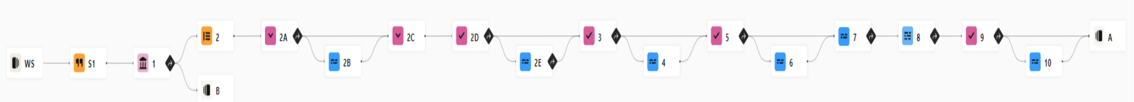
[2] Information gathered via this exercise is subject to the ICES data privacy statement. See http://www.ices.dk/Pages/Privacy-statement---meetings.aspx for further information.

# Online survey format and questions developed and distributed by the Aquaculture Overviews Operational Group (Annex 3)

The survey questions and logic were as follows.



| | |
|---|---|
| WS | <br> <br>Stakeholder engagement survey to design the ICES Aquaculture Overviews<br>ICES seeks to develop aquaculture overviews that are highly relevant to all stakeholders, will inform decision-makers, and are based on the best available science and information. |
| S1 | You are receiving this survey on the ICES Aquaculture Overviews because an ICES national aquaculture nominee identified you or your organization as an important national-level stakeholder on sustainable aquaculture.<br>*To continue, press "enter"* |
| 1 | Information gathered via this process is subject to the ICES data privacy statement http://www.ices.dk/Pages/Privacy-statement---meetings.aspx . To continue, please click that you accept these conditions.<br>*Select an option*<br>A: I accept<br>B: I don't accept *(this option ends the survey)* |
| 2 | Tell us about your work |

| | |
|---|---|
| | *To continue, press "enter"* |
| 2a | Which category best describes the organization that you work for?<br>*Type or select an option*<br>Government regulatory agency<br>Government scientific agency<br>Academic institution<br>Non-Governmental Organization (NGO)<br>Private Industry<br>Other |
| 2b | If "other", please describe the organization that you work for here.<br>*(open text field)* |
| 2c | In which ICES country are you located?<br>*Type or select an option*<br>Belgium<br>Canada<br>Denmark<br>Estonia<br>Finland<br>France<br>Germany<br>Iceland<br>Ireland<br>Latvia<br>Lithuania<br>The Netherlands<br>Norway<br>Poland<br>Portugal<br>Russian Federation<br>Spain<br>Sweden<br>United Kingdom<br>United States of America<br>Other |
| 2d | In your work, do you mostly deal with:<br>*Choose as many as you like*<br>A Policy development<br>B Management decisions<br>C Regulatory decisions<br>D Science<br>E Other |
| 2e | If "other", please describe the focus of your work here.<br>*(open text field)* |

| | |
|---|---|
| 3 | What management objectives/issues require advice?<br>*Choose as many as you like*<br>A Carrying capacity and efficiency of aquaculture systems<br>B Genetics of cultured taxa<br>C Environmental impacts and mitigation options<br>D Pathology and diseases<br>E Vulnerability/resiliency to environmental/climate change<br>F Social impacts<br>G Economic impacts<br>H Future projections<br>I Other |
| 4 | If “other, please describe the management objectives/issues require advice here.<br>*(open text field)* |
| 5 | What general information should the overviews contain?<br>*Choose as many as you like*<br>A Description of aquaculture practices<br>B Regional patterns in aquaculture production<br>C Cultured taxa<br>D Relevant social information<br>E Relevant economic information<br>F Seafood safety policies and laws<br>G Relevant mitigation strategies<br>H Other |
| 6 | If “other”, please describe what information the ICES Aquaculture Overviews should contain.<br>*(open text field)* |
| 7 | What areas of information are currently lacking that that could help support management or regulatory decisions in your field?<br>*(open text field)* |
| 8 | Briefly explain how you use science to inform your decisions with respect to aquaculture.<br>*(open text field)* |
| 9 | How should the ICES Aquaculture Overviews be presented or displayed?<br>*Select an option*<br>- An online, interactive format or webpage<br>- Traditional document or .pdf<br>- Other |
| 10 | If “other”, please explain how you would like the Aquaculture Overviews presented<br>*(open text field)* |
| A | Thank you for participating in the ICES survey on stakeholder engagement to design the ICES Aquaculture Overviews. Please contact Anne.Cooper@ices.dk for further information. |