WORKING GROUP ON ENVIRONMENTAL INTERACTIONS OF AQUACULTURE (WGEIA)

VOLUME 2 | ISSUE 112

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

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ISSN number: 2618-1371 I

ICES Scientific Reports

Volume 2 | Issue 112

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Recommended format for purpose of citation:

ICES. 2020. Working Group on Environmental Interactions of Aquaculture (WGEIA). ICES Scientific Reports. 2:112. 187 pp. http://doi.org/10.17895/ices.pub.7619

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Contents

i Executive summary

Most of the aquaculture production today takes place in Asia. In 2018, ICES countries reported a relatively modest production of 3.3 mill. metric tonnes from freshwater (1.1%), brackish water (8.5%) and marine (80.4%) aquaculture. Efforts are now being made to increase sustainable aquaculture in ICES countries, and in particular of marine aquaculture.

Environmental impacts are one of the factors limiting aquaculture growth, and Working Group on Environmental Interactions of Aquaculture (WGEIA) has prioritized areas where improved aquaculture management can lead to better environmental performance of the aquaculture industry. WGEIA has reviewed laws and regulatory standards for monitoring and managing environmental impacts of marine aquaculture, and the corresponding thresholds values established by contributing ICES countries with the aim of improving current management options. China, the main contributor to global marine aquaculture (ToRa) was also included in this review.

For each country considered in the review, responsible agencies, laws and regulations, monitoring, mitigation, and knowledge gaps were identified for each of the following issues: effluents pathogens/parasite transfer, genetic and ecological issues (finfish), and effluents, pathogens, escapes, interaction with wild species, effects on sensitive habitat/spawning areas (shellfish). Variations in the regulatory systems dealing with the main risks issues were found between countries. In general, the regulatory and monitoring systems for organic waste are well developed, but to a lesser and varying degree for the other challenges.

WGEIA makes recommendations for prioritized research to elucidate knowledge gaps in aquaculture-environment interactions that are needed for effective industry regulation for the main risk issues (ToRb).

Looking ahead, a follow-on working group ("Risk assessment of Environmental Interactions of Aquaculture; WGREIA) will be established to (1) publish the main results from WGEIA in a peer-review journal and (2) address and publish risk assessment methods for environmental impacts of aquaculture.

ii Expert group information

Expert group name	Working Group on Environmental Interactions of Aquaculture (WGEIA)
Expert group cycle	Multiannual fixed term
Year cycle started	2018
Reporting year in cycle	3/3
Chair	Terje Svåsand, Norway
Meeting venue(s) and dates	11-14 December 2019, ICES HQ, Copenhagen Denmark (20 participants)
	3-5 September 2019, Scotland, UK (17 participants)
	5-7 May 2020, online (25 participants)

1 Introduction

Aquaculture as a way of producing human food has a long history, with Chinese aquaculture going more than 3000 years back in time (Liao and Huang, 2000; Teletchea and Fontaine, 2014). Historically, production have included a multitude of species including fish, molluscs, crustaceans and seaweed.

For the last 20 years, the global wild capture of molluscs, crustacean and fish has been nearly stable around 90 mill. metric tons. Aquaculture production, in turn, has increased from 28 to 81 mill. metric tons (FAO, 2020). In 2018, aquaculture accounted for 46% of the global production of molluscs, crustacean and fish and has become a very important source for healthy seafood and is still increasing every year. Most of the aquaculture production is located in Asia, and efforts are now being made to increase sustainable aquaculture also in the ICES countries.

The aquaculture production in the ICES countries was 3.3 mill. metric tons in 2018 (Figure 1.1), whereof 1.1 %, 8.5%, and 80.4% came from freshwater, brackish water and marine aquaculture, respectively.

Finfish aquaculture has increased yearly since the 1980ies (mainly Atlantic salmon), while the production of molluscs has been stable around 700.000 tons since 1970. The production of crustacean (mainly from brackish water) has increased a little but are still at a low level (75.000 tons in 2018).

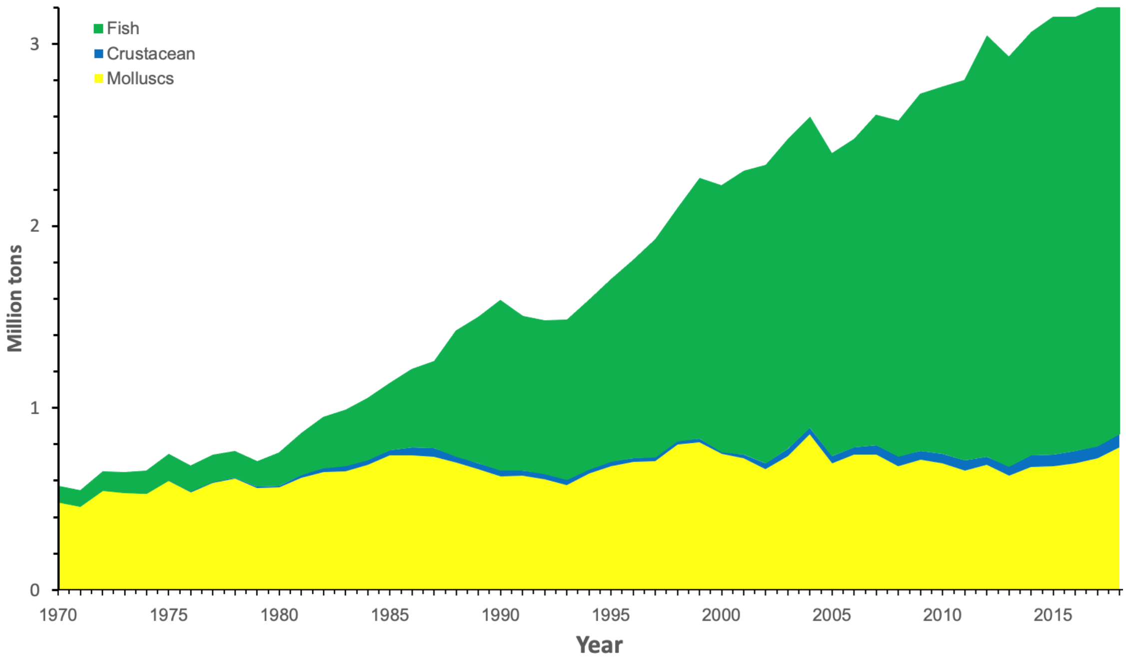

Figure 1.1. Aquaculture production of molluscs, crustacean, and finfish in the period 1970-2018 freshwater, brackish water and marine waters) (FAO, 2020).

Of the marine aquaculture production in 2018, finfish (70%) and molluscs were the dominant groups (Figure 1.2)

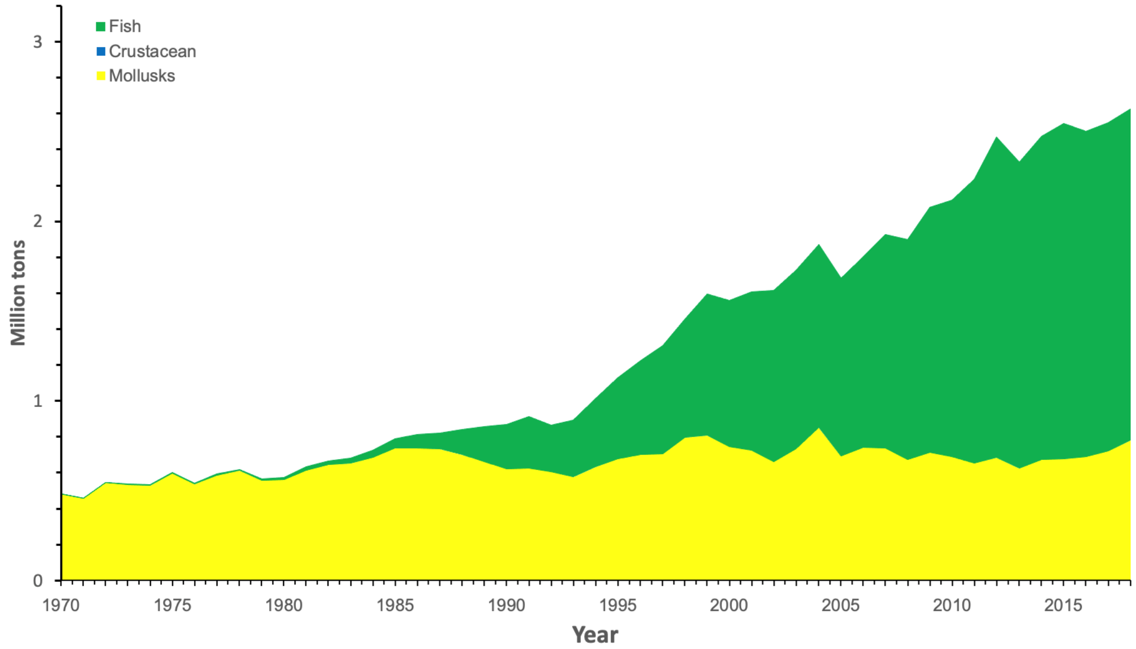

Figure 1.2. Marine aquaculture production of molluscs, crustacean, and finfish in the period 1970-2018. Production of crustacean was only 2000 tons in 2018 and are not seen in the figure (FAO, 2020).

Environmental impacts are one of the limitations for further aquaculture growth, and WGEIA has prioritized areas where improved aquaculture management can lead to better environmental performance of the aquaculture industry. The tools needed for sustainable development and management rely on a better understanding of how such farming interacts with the environment.

WGEIA has reviewed laws and regulatory standards for monitoring and managing environmental impacts of marine aquaculture, and the corresponding thresholds values established by ICES countries with the aim of improving current management options. China, the main contributor to global marine aquaculture was also included in this review. Further, we give recommendations for prioritized research to elucidate knowledge gaps in aquaculture-environment interactions needed for effective industry regulation.

The work in WGEIA fits very well into science priorities “Impacts of human activities”, “Seafood production” and “Sea and Society” in the new Science Plan for ICES. The main focus will be on marine aquaculture (Figure 1.2)

Marine aquaculture production in the ICES countries are mainly finfish and molluscs. The production of crustacean is small and will not be addressed in this report. The environmental impacts are different between finfish and molluscs and will be addressed separately in sections 3 and 4, respectively.

2 Marine aquaculture production in the ICES countries, status and trends

Marine aquaculture production within the ICES countries in 2018 accounted for 2,64 million tons of diverse species of finfish, molluscs, and crustaceans. The major producer within ICES countries was Norway accounting for more than half of the total production. Followed by Spain with over 12%, followed by France, UK and USA with over 8%. Canada produces over 7%, while Netherlands and the small archipelago of the Faroes Islands, each produces almost 3% of the total production within the ICES countries (Table 2.1)

Table 2.1. Marine Aquaculture Production in tons live-weight by ICES country in 2018 (FAO, 2020).

ICES countries	Crustacean	Molluscs	Finfish	Total	Share %
Canada	0	43,321	137,828	181,149	6.8 %
Denmark	0	4,516	9,737	14,253	0.5 %
Estonia	0	0	0	0	0.0 %
Faroe Islands	0	0	78,900	78,900	3.0 %
France	0	144,845	4,490	149,335	5.6 %
Germany	0	15,944	0	15,944	0.6 %
Iceland	0	108	29	137	0.0 %
Ireland	0	24,315	11,984	36,299	1.4 %
Netherlands	0	45,600	20	45,620	1.7 %
Norway	27	1,695	1,353,091	1,354,813	51.2 %
Portugal	0	6,326	3,480	9,806	0.4 %
Russian Federation	151	9,562	20,660	30,373	1.1 %
Spain	15	285,300	48,556	333,871	12.6 %
Sweden	0	1,986	2,870	4,856	0.2 %
United Kingdom	0	17,142	169,575	186,717	7.1 %
United States of America	2,035	181,228	20,424	203,687	7.7 %
Total	**2,228**	**781,888**	**1,861,644**	**2,645,760**	**100.0%**

The accumulated marine aquaculture production in the last 20 years shows the same trends from year 2018, with no major variation in the countries' production. Finfish is the most harvested category, led by Norway with almost two thirds of the total finfish production, followed by UK and Canada and the Faroe Islands (Table 2.2). Molluscs production accounts for almost a third of the marine aquaculture within ICES, which is led by Spain, closely followed by France, USA and Netherlands. The later shows country specialization and a diverse distribution of production systems among the ICES countries.

Table 2.2. Marine Aquaculture Production in tons live-weight by ICES country from 1998 – 2018 (FAO, 2020).

ICES country	Crustacean	Molluscs	Finfish	Total	Share %
Canada	0	765,993	2,371,850	3,137,843	7.31%
Denmark	0	20,757	189,950	210,707	0.49%
Estonia	0	0	0	0	0.00%
Faroe Islands	0		1,167,166	1,167,166	2.72%
France	0	3,588,535	127,217	3,715,752	8.66%
Germany	0	298,720	249	298,969	0.70%
Iceland	0	963	39,995	40,958	0.10%
Ireland	13	667,419	313,137	980,569	2.28%
Netherlands	0	1,193,962	180	1,194,142	2.78%
Norway	528	45,226	19,075,923	19,121,677	44.55%
Portugal	0	75,165	71,495	146,660	0.34%
Russian Federation	679	42,667	124,499	167,845	0.39%
Spain	1,451	4,670,538	684,129	5,356,118	12.48%
Sweden	0	31,340	44,313	75,653	0.18%
United Kingdom	0	483,158	3,180,794	3,663,952	8.54%
United States of America	58,892	3,215,851	373,383	3,648,126	8.50%
Total	**61,563**	**15,100,294**	**27,764,280**	**42,926,137**	

The total production trend of marine aquaculture within ICES presents steady growth since year 2000 as shown in (Figure 2.1).This trend is led primarily by finfish production. Molluscs and crustaceans production presents the opposite trend, decreasing since early 2000s with a slight increase from 2012 onwards.

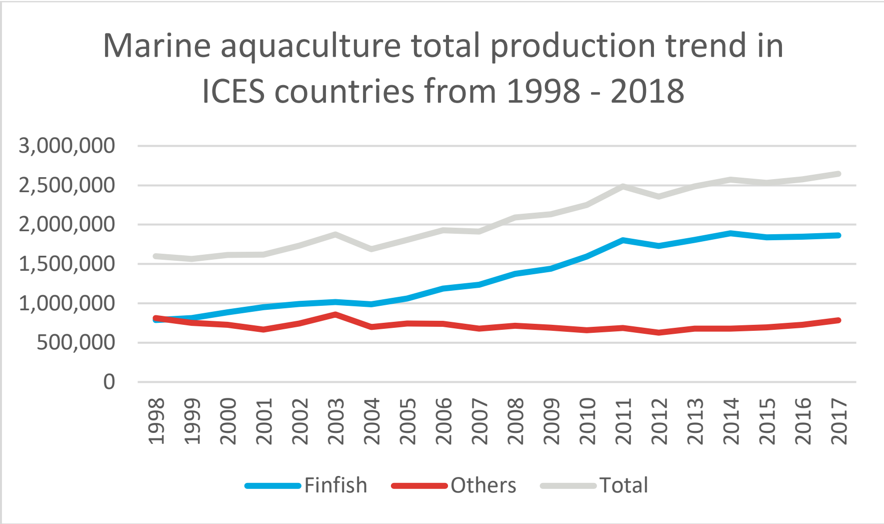

Figure 2.1. Total Aquaculture Production in ICES countries from 1998 - 2018 in tons live weight (FAO 2020).

Finfish production shows a steady increase since early 2000s, as shown in following the production dynamics from Norway (Figure 2.2) producing a million tons of finfish on average over the last 20 years. Norway dominates the production of finfish in ICES with the culture of Atlantic salmon, which represents almost 60% of the total marine aquaculture production in ICES countries (Table 2.3). Other representative producers of finfish in ICES are United Kigdom, Canada, Faroe Islands and Spain respectively, although each of them produce below 150.000 tons live-weight per year. All these countries, with the exception of Spain, also produce mainly Atlantic salmon.

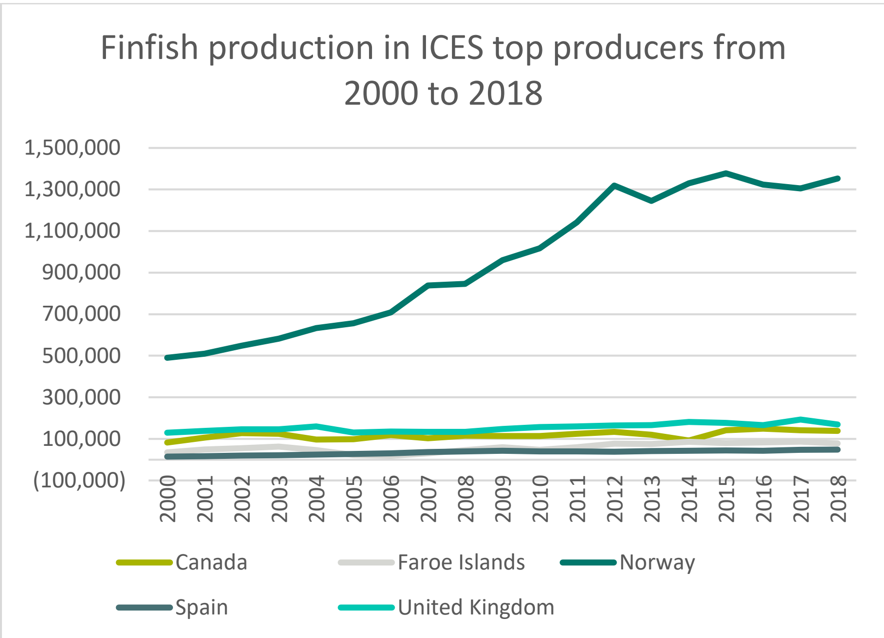

Figure 2.2. Finfish production in ICES top producers from 2000 to 2018.

Production of molluscs and crustaceans presents more variable trends as shown in Figure 2.3. Spain, USA and France are the most representative producers in this category. Spain is the lead producer with the culture of sea mussels (see Table 2.2), maintaining its position through the 20 years of analysis (Figure 2.3). Currently the second most representative producer is USA with the production of American cupped oysters and Northern quahog (hard clam), their aquaculture production in tons live-weight has increase in the past 7 years as depicted in Figure 2.3. France follows with the culture of blue mussels and pacific cupped oysters. Netherlands, Canada and Ireland also contribute to the production of molluscs and crustacean, although to a lesser extent.

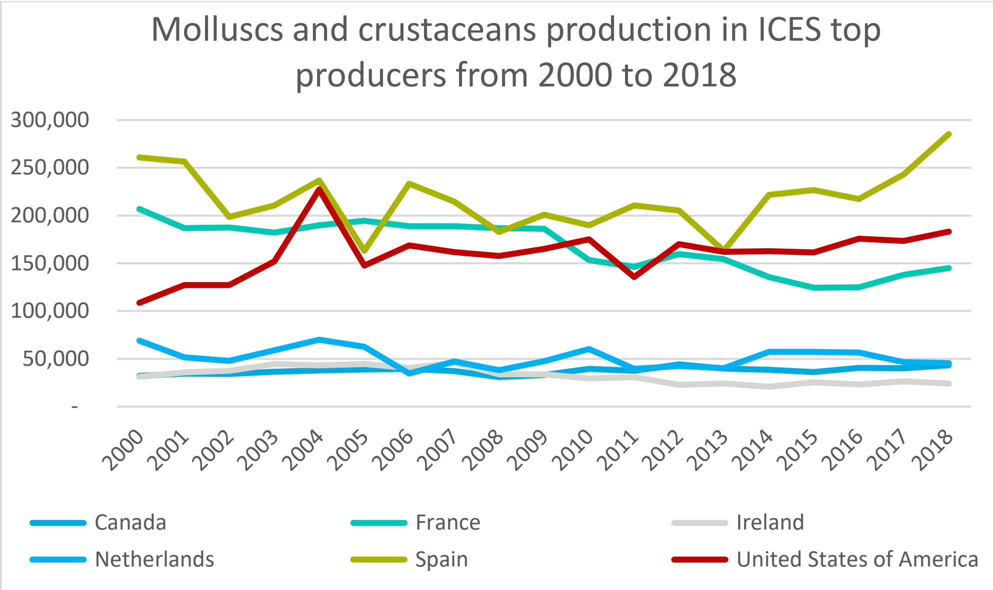

Figure 2.3. Molluscs and crustaceans' production in ICES top producers from 2000 to 2018

The most farmed species along the ICES countries are listed in (Table 2.3). Atlantic salmon dominates with almost 60% of the total aquaculture production within ICES countries. Atlantic salmon represents 89% of the finfish production in ICES, followed by rainbow trout with only 6.5%. The production of molluscs and crustaceans presents more diversity in terms of the species farmed. Sea mussel is the leading species with a 30.6% share in this category and close to 11% share in the total marine aquaculture production in ICES. The main producer of sea mussels is Spain. The following most representatice species are blue mussel and pacific cupped oyster with 9.5% and 7.3% of the total production in ICES, respectively. The main producer of both these species is France. USA contributes to this category with the production of american cupped oyster and northern quahog (hard clam), accounting for 4.3% and 1.4% of the total production, respectively.

Table 2.3. ASFIS species share in marine aquaculture production within ICES countries accumulated production last 20 years (1998-2018) - (FAO, 2020).

ASFIS Species	Total production	Share in total production	Share finfish production	Share in other species prod.	Lead producer
American cupped oyster	1,833,654.0	4.3%	0.0%	12.1%	**USA**
Atlantic salmon	24,630,144.3	**57.4%**	88.7%	0.0%	**Norway**
Blue mussel	4,098,527.0	**9.5%**	0.0%	27.0%	**France**
Northern quahog (=Hard clam)	592,459.4	1.4%	0.0%	3.9%	**USA**
Pacific cupped oyster	3,137,657.5	**7.3%**	0.0%	20.7%	**France**
Rainbow trout	1,777,148.9	4.1%	6.4%	0.0%	**Norway**
Sea mussels nei	4,636,092.9	**10.8%**	0.0%	30.6%	**Spain**
Grand Total	**42,926,137.0**	**100.0%**			
Finfish species	**27,764,280.4**	*64.7%*			
Molluscs and crustaceans	**15,161,856.7**	*35.3%*			

* ASFIS: Aquatic Sciences and Fisheries Information System

At the regional level, Europe is the lead producer of both categories finfish and others (molluscs and crustacean) with 84% of the total production for the last 20 years (Table 2.4). As explained above this is lead by the production of finfish. The North American countries represented in ICES account for 16% of the total marine aquaculture production within ICES.

Table 2.4. Total marine aquaculture production in ICES countries from 1998 - 2018 (Source: FAO 2020)

ICES Region	Total Aquaculture Production 1998 - 2018	Share %
North America	6,785,969	15.8%
Finfish	2,745,233	6.4%
Molluscs and crustaceans	4,040,736	9.4%
Europe	36,140,168	84.2%
Finfish	25,019,047	58.3%
Molluscs and crustaceans	11,121,121	25.9%
Total	**42,926,137**	

The production trends at the regional level follow the trends described above. Finfish production shows a constant increase since early 2000s lead by Norwegian production of Atlantic salmon showed Figure 2.4, whilst molluscs and crustaceans showed a declining trend until 2012 with a sligh increase in the last years, mainly pushed by spanish production of sea mussels as showed in Figure 2.5.

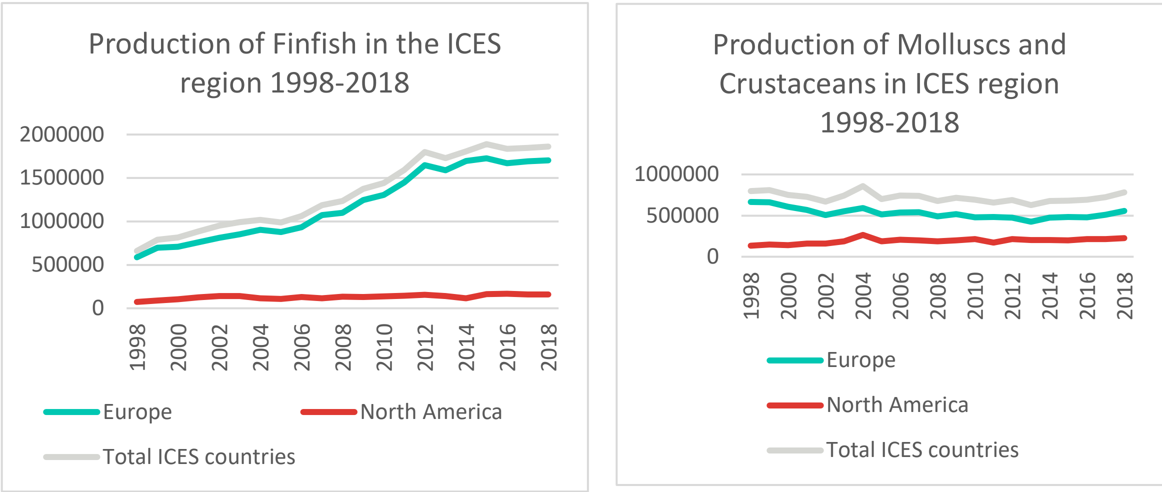

Figure 2.4. Development of aquaculture production in the ICES region from 1998 - 2018 in tons live weight (FAO, 2020).

Marine aquaculture production in China

China's aquaculture industry has grown markedly for more than six decades (Figure 2.5), increasing from fewer than 100,000 tons in 1950, to 9.54 million tons (Mt) in 1993, the year overtook the volume of catch fishery, and further increasing to a record 51.4 Mt in 2016. China now produces considerably more aquatic products through aquaculture than wild capture fisheries in both marine and freshwater. During this rapid growth, aquaculture has made significant contributions to safeguarding market supply, increasing rural income, improving the export competitiveness of agricultural products, improving people's diets and guaranteeing food security.

China has been the top fish producer globally for many years. In 2018, China (mainland only) produced 61 Mt of food fish, with 46.7 Mt (75 percent) from aquaculture and 14.3 Mt (25 percent) from capture (BOF, 2019). Chinese aquaculture enjoyed double-digit growth rates in the 1980s and 1990s, but in the new millennium (2001–2015) the average annual growth decreased to 5.4 percent, lower than that of the rest of Asia. The growth rate has shown further a slightly decreasing trend over the last two years. There are many reasons behind this slowdown in aquaculture expansion, such as the policy limit on aquaculture space usage, the pressure on clean-up of discharge, and the marginalized profits due to the continuous rise in labour and other costs. Although aquaculture is still strategically encouraged by the government, more rapid growth in China aquaculture is unlikely to happen in the near future.

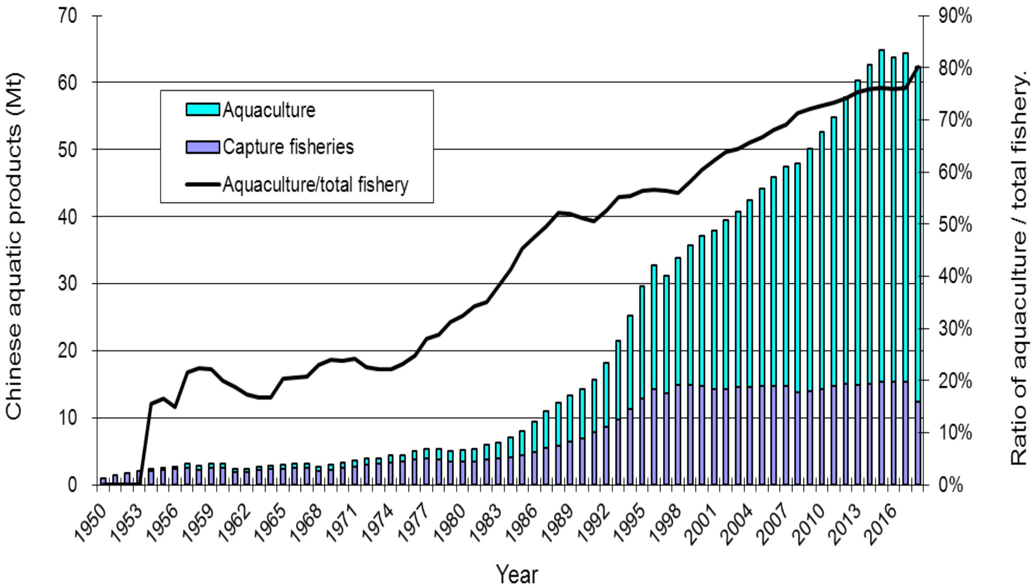

Figure 2.5. Aquaculture and capture fisheries production in China, 1950-2018 (BOF, 2019)

When comparing the production of marine aquaculture in China with the regional production in ICES, Chinese production dominates in all categories. Europe has a representative participation in the production of finfish, as described in previous section mainly due to the culture of Atlantic salmon in Norway.

Table 1.5. Overview of total marine aquaculture production in China and the ICES regions of finfish, molluscs and, crustaceans and jellyfish in tons live weight from 1998 to 2018 (FAO, 2020).

ICES region and China	Finfish	Crustaceans and Jelly-fish	Molluscs	Compound production China and ICES
China	77,970,797	2,401,408	160,413,521	240,785,726
Europe	25,019,047	2,671	11,118,450	36,140,168
North America	2,745,233	58,892	3,981,844	6,785,969
Total	**105,735,077**	**2,462,971**	**175,513,815**	**283,711,863**
Share	**37.3%**	**0.9%**	**61.9%**	

China compared with Europe is a main producer of molluscs with a total production of 160,4 million tons live-weight during the last 20 years, more than ten times the production of Europe and North America compound. In finfish, Chinese production triples the production of ICES regions combined.

The main species farmed in China (Table 2.6) differ from those farmed in ICES regions except for sea mussels that are also extensively farmed in Spain (Table 2.3). The most farmed species in China is cupped oysters, which are also farmed in France and USA, however different varieties

(Pacific cupped oyster and American cupped oyster). Japanese carpet shell and scallops are also a representative species farmed in China.

Table 2.6. Main ASFIS species in marine aquaculture production in China accumulated production from 1998 to 2018

ASFIS Species	China	Share in Chinese production	Share in total ICES regions and China
Cupped oysters nei	76,169,772	31.6%	26.8%
Japanese carpet shell	61,317,158	25.5%	21.6%
Marine fish nei	6,705,825	2.8%	2.4%
Scallops nei	25,351,555	10.5%	8.9%
Sea mussels nei	13,660,050	5.7%	4.8%
Total China	**240,785,726**		
Total China and ICES regions	**283,711,863**		

Marine aquaculture yearly production in China and in ICES countries has increased steadily as shown in Figure 2.6. The compounded yearly production starts from 8 million tons live-weight in 1998 to over 18 million tons, more than doubling yearly production in the span of 20 years. China has remarkably increased its production of both finfish and other species, such as molluscs, crustaceans and jellyfish during the last 20 years. The production of finfish has more than almost quadrupled starting from 1.5 million tons in 1998 to 5.5. million tons in 2018. The annual production of other species such molluscs, crustaceans and jellyfish have doubled in the analysed time span, starting from 5.1 million in 1998 to 10.5 million in 2018. During the last three years (2016 to 2018) marine aquaculture production in China, has increased notably.

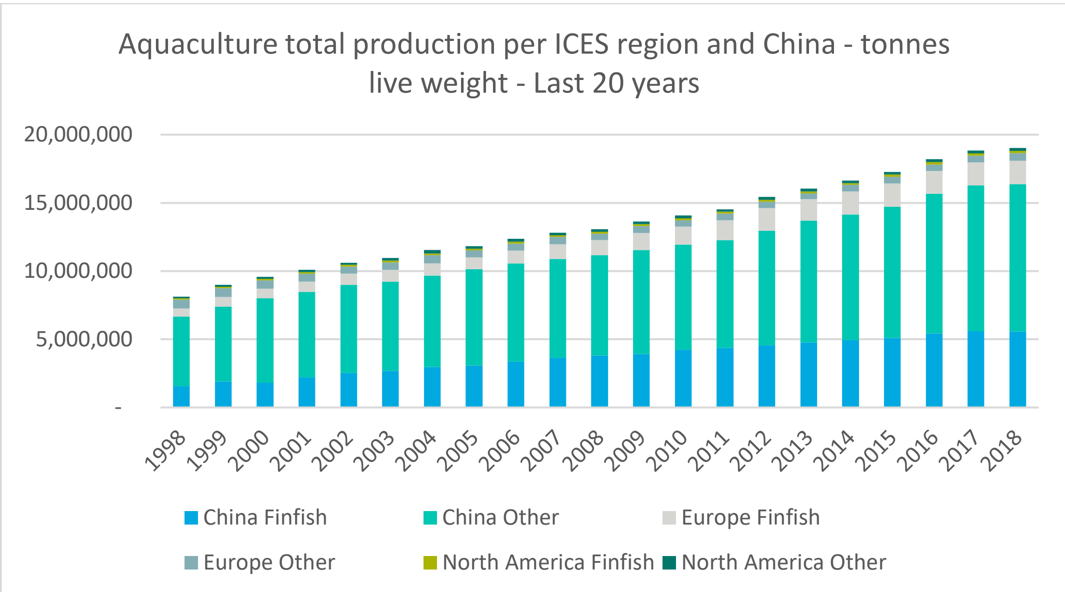

Figure 2.6. Marine aquaculture production from 1998 - 2018 in China and ICES regions of finfish and others (molluscs, crustaceans and jellyfish) in tons live weight (FAO, 2020).

The production dynamics in the two ICES region show a more stagnant trend, the main contributor to the growth in marine aquaculture production is finfish in Europe, pushed mainly by Norway, where the yearly production has more than triple in the 20 years of analysis, starting from over 587 thousand tons to 1.7 million tons live-weight. The production of molluscs and crustaceans has decreased in Europe from 665 to 557 thousand tons. In the ICES countries in North America, the production of finish is stagnated around the 150 thousand tons live-weight mark, whilst molluscs and crustacean's yearly production has increased from 134 to 226 thousand tons from 1998 to 2018.

In a recent publication from the Working Group on Scenario Planning on Aquaculture (WGSPA), analysed and analysed past trends in farmed and wild seafood production and consumption in ICES countries, as well as the potential and need to increase aquaculture production by 2050 (Froehlich *et al.*, 2020).

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3 Environmental impacts and recommendations for future prioritized research – finfish aquaculture

Historically, production of finfish has included various practices like intensive farming, stocking to strengthen fisheries, ocean ranching and several ways of culturing a habitat to make it suitable for semi-natural production and harvesting. In this chapter, however, we will focus on production of farmed fish in enclosed production units. There are large variations in the scale of production. Atlantic salmon is the main finfish produced in ICES, and will also have the focus in this chapter, but also with reference to other finfish species.

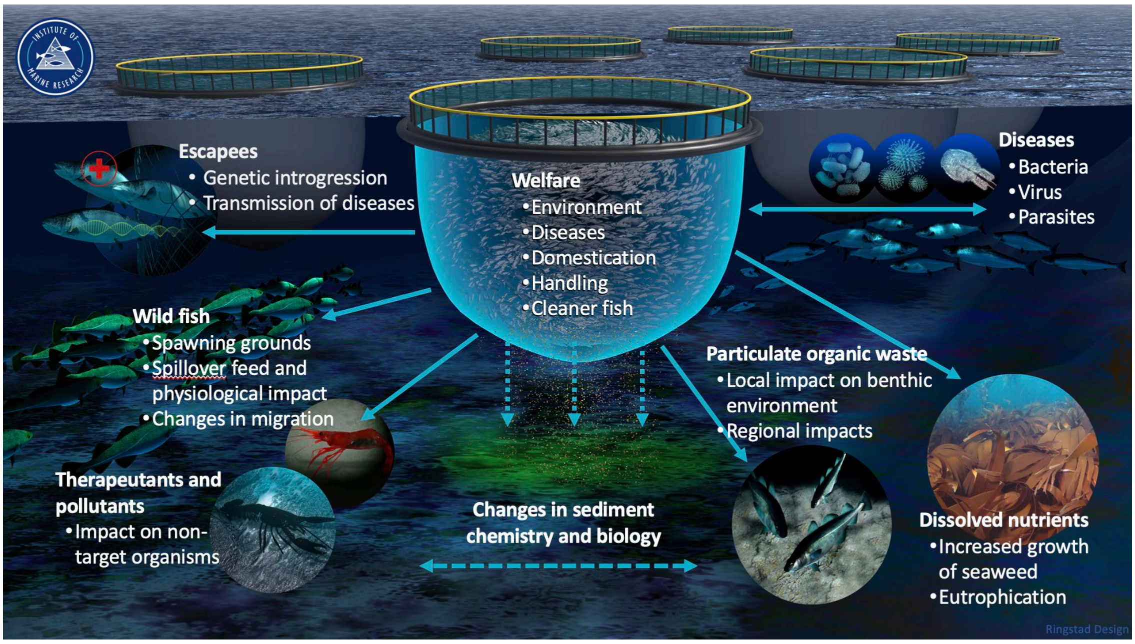

Figure 3.1 Illustration of environmental impacts of salmon farming in Norway (Grefsrud, IMR, 2019).

According to the Norwegian risk assessment report (Grefsrud *et al.*, 2019) and Figure 3.1, the main environmental impacts from open cage fish farming can be grouped as effluents, pathogen/parasite transfer, genetic and ecological issues, and emerging issues as use of cleaner fish.

3.1 Effluents

3.1.1 Background and structure

3.1.1.1 Effluent composition – an evolving stressor

Effluents from fish farms come from feed spill, faeces, medications and cleaning of the net pens. The main source is feed, and we will start with addressing the Atlantic salmon diet. Typically, modern extruded diets for Atlantic salmon contain approximately 18% marine protein, 37% plant protein, 11% marine lipids, 19% plant lipids and 11 % carbohydrates (Ytrestøyl *et al.*, 2015). The feed materials have changed considerably over the past 30 years, when salmon feed was approximately 65% marine protein and 24% marine lipids. Changing feed materials alters the nutrient and contaminant composition of the feed (Sissener *et al.*, 2013) and as such the composition of the farm effluents. During feed formulation the macronutrient composition of the feed will be balanced out and often vitamin and mineral premixes are added to ensure the feed meets the fish's nutrient requirements. Reduction of marine ingredients has resulted in reduced levels of dioxins, PCB's and dioxin-like PCB's (Nøstbakken *et al.*, 2015). On the other hand, contaminants associated with plant ingredients, like pesticides and mycotoxins, may be introduced to the diets (Pietsch, 2019; Oliveira and Vasconcelos, 2020). Though there is little evidence (as yet) of related environmental problems. Moreover, the micro-minerals that are required by the fish that can also pose a threat to the surrounding environment (e.g. zinc, copper, selenium) may change quite considerably between marine and plant ingredients. As the quantities of the various ingredients change so does the availability of the minerals for the fish (Prabhu *et al.*, 2016). Depending on their availability and uptake in the fish, certain nutrients (e.g. zinc and copper) and contaminants will concentrate in the faeces, resulting in much higher levels of these compounds in the farm-derived effluents compared to the feed.

Feed optimization is traditionally driven by optimizing the feed conversion ratio, which is the ratio between feed gift and fish growth. This is balanced with other factors, like fish welfare, fillet quality and fillet composition. However, upper limits of e.g. minerals (zinc, copper, selenium) in feed have been reduced in the past years due mostly to environmental concerns, and regulatory limits are expected to become even more stringent in future. It can be expected that environmental considerations will become more important in feed formulations since: 1) we are increasing our knowledge of farm-derived effluents, 2) new technologies will allow for aquaculture sludge to be collected and its use could be limited due to high mineral and contaminant levels in the sludge (Aas *et al.*, 2016).

3.1.1.2 Division of issues for this report

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. Recent estimates indicate a feed to faeces conversion factor of approximately 20% (by mass dry weight: Cubillo *et al.*, 2016). Additionally, a large proportion (60-80%) of the nutrients (nitrogen and phosphorus) that are supplied with the fish feed enter the water column in a dissolved form (Jansen *et al.*, 2018). The many changes to the diets that have occurred in recent years have altered digestibility, however, the implications of this for waste production are yet to be properly quantified. The digestibility of the feed is also species-specific, for example, it can be as low as 15% for sea bream and sea bass (Cromey *et al.*, 2012). Given that a small proportion of the feed is not eaten (i.e. waste feed), the particulate load can be viewed in two components: 1. faeces and the non-digestible component of the feed, and 2. waste feed pellets.

Therefore, for the purposes of this report, the waste discharged from fish farms has been divided into three main groups, being: 1) the solid or particulate organic components, 2) the dissolved organic and inorganic component, and 3) the contaminants, and therapeutants that are either associated with the waste or discharged during other routine farming practices, with focus on Atlantic salmon farming.

3.1.2 Organic waste

3.1.2.1 Waste particulates

Cause

Particulate waste from sea-based fish farms enters the marine environment in two primary forms: waste feed (uneaten pellets) and fish faeces. The larger feed pellet particles sink to the seabed at rates of between 2 and 12 cm/s (Cromey *et al.*, 2000) while the smaller, less dense faeces sink at rates of between 0.5 and 5 cm/s (Bannister *et al.*, 2016). As such 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).

Estimates for waste feed have varied greatly over the years, from 30 % in the early days of fish farming, down to a more realistic 5 % with the advent of moist extruded feeds (Findlay and Walting, 1994; Brooks and Mahnken, 2003), and in most modern facilities farm managers argue that it is closer to 1 %. It is however difficult to obtain accurate measurements because the bulk of the waste feed is released during feed spills (i.e. from equipment malfunctioning), which are both episodic and unpredictable. Moreover, there is likely to be considerable differences between farms due to the vastly different feeding systems that are available (from manual to fully automated) and how farms are managed (e.g., Ellis *et al.*, 2016; Zhou *et al.*, 2018). Many older waste dispersion models conservatively use waste feed levels between 5% and 10% (Cromey *et al.*, 2002, 2009, 2012), but can be as high as 52% depending on species and site-specific factors (e.g., sea bream and sea bass, Ballester-Moltó *et al.*, 2017). As such, protein-rich waste feed remains a highly variable but potentially significant supply of organically rich material to the seabed. It is relevant to add here that in many cases the excess fish feed is readily consumed by the wild fish (e.g., Fernandez-Jover *et al.*, 2011), which mitigates the enrichment effects to an unknown extent.

Of the approximate 30 % of the feed that is discharged to the environment via excretion, an estimated 25-30 % is in solid form and is deposited on the seabed. With respect to feed-sourced carbon, approximately 62 % is lost into the environment, 30 % of which is released as particles and the remainder respired as CO_2 (Wang, *et al.* 2013). For nitrogen, 57 % is released into the environment, of which 26 % is particulate and the remainder dissolved, principally in ammonia form (Wang, *et al.* 2013). Quantifying aquaculture waste into different waste fractions is also dependent on several factors including feed composition, feed quality and fish species. For example, for juvenile rainbow trout, on average 48% of the ingested N was recovered in the water in dissolved soluble form and 7% in solids (particulate), and for P 1 % of the ingested P was recovered in the water and 43% in the solids (Dalsgaard and Pedersen, 2011). The discharge rates of particulate waste can be significant, for example a single capacity farm can produce depositional fluxes as high as 70 gTPM m^{-2} d^{-1} beneath the cages (Keeley *et al.*, 2019). Hence, there is a significant flux of carbon and nitrogen rich waste particles being transported to the seabed with considerable potential for organic enrichment.

The discharge of waste particles is also the mechanism for the dispersal of the other compounds that can be associated with the feed, such as zinc, which is an important nutrient in salmon feeds. Feed related contaminants are discussed in more detail in Section 3.1.3

Potential ecological effects

Biodeposits from fish farms can cause severe benthic organic enrichment (and contamination – discussed under section 3.1.3) 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. In conjunction with the severe enrichment of organic carbon, the redox potential becomes strongly negative and toxic total free sulphide concentrations can become highly elevated and outgassing of both sulphide and methane gases can result (Wildish *et al.* 2004, Hargrave *et al.* 1997). Benthic effects grade progressively with distance away from the farm achieving natural conditions within 200-1000m away (Kutti *et al.*, 2007; Keeley *et al.*, 2013, 2019; Broch *et al.*, 2017)

Spatial extent and severity of effects are highly site-specific in response to a number of factors, but most critically, the dispersive nature of the receiving environment (Keeley *et al.*, 2013; Bannister *et al.*, 2014; Keeley *et al.*, 2019). As a 'rule of thumb' sheltered low flow sites are associated with severe enrichment that can impact overlying waters due to deoxygenation and emission of toxic gases, but it is constrained to an area immediately beneath the cages. Conversely, highly dispersive sites can have a much more diffuse footprint, avoiding severe enrichment beneath the cages, and accordingly maintain a more functional benthos that has a more rapid recovery timeline. The disadvantage being that the total size of the affected area is much greater, with increased potential for overlapping effects (with other farms, sensitive habitats or commercial species etc.).

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 substrates 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 larger epibiota or reef-dwelling species are generally poorly documented. Organic waste can be found in body tissues of a wide range of fauna at least 1 km from farms using sensitive tracing techniques (e.g., stable isotopes, DNA and terrestrial fatty acid markers, Woodcock *et al.*, 2017, 2018). In these situations, the size of the area of influence can be very large, but it is normally at low levels and the ecological implications are either minor or poorly understood. Negative effects to sensitive and / or valuable species or habitats are a related issue that occasionally warrants specific attention, for example maerl beds (Hall-Spencer *et al.*, 2006; Sanz-Lazaro *et al.*, 2011), corals (Bongiorni *et al.*, 2003) and seagrass habitats (Cancemi *et al.*, 2003).

Interactions with wild fish is closely related and an important issue that has received a reasonable amount of attention in some regions (e.g., Dempster *et al.*, 2009, 2002). Waste feed plays a significant role in this interaction, but there are a number of other influencing factors. See Callier *et al.* (2018) for a review.

3.1.2.2 Dissolved waste component

Cause

By far the majority of the nitrogen that is produced from salmon and trout farms is in the dissolved form (up to 80-90%) whereas for phosphorus approximately 27% of the effluent is in dissolved form (Reid *et al.*, 2008; Dalsgaard and Pedersen, 2011). Dissolved discharge can also include copper by ablation from antifouling on structures and zinc from feeds.

Potential effects

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 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). Harmful algal occur naturally in the environment, but when present the extent of the blooms can be exacerbated by the presence of additional nutrients. Harmful algae blooms can be toxic to humans, marine life and cause closures of shellfish harvesting operations, depending on species and associated toxins (Hallegraeff *et al.*, 1995; Anderson *et al.*, 2008). Decomposition of phytoplankton can lead to oxygen depletion especially in poorly flushed, shallow water bodies.

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, and the addition of nutrients is generally not perceived to be a negative issue. Well flushed sites are particularly unlikely to experience any measurable changes in water column nutrients of plankton concentrations (Jansen *et al.*, 2018). Studies to date on the effects on concentrations a short distance from the farm or on the growth and productivity of macroalgae or bivalves often yield conflicting results, and many suggest that the potential for effects is negligible (e.g. Lander *et al.*, 2013; Price *et al.*, 2015). For establishing fish farms in more eutrophicated seas, site selection can be a prerequisite so as to avoid significant eutrophication related impacts. Further using compensatory farming e.g. mussel farming can be a tool to compensate for N and P effluents (Lander *et al.* 2013; Fossberg *et al.*, 2018).

Hydrodynamic three-dimensional models can be used to investigate if there is likely to be any significant impact of effluent from a fish farm in the receiving water bodies and vulnerable habitats.

3.1.2.3 Regulation of organic waste

The regulation of organic waste, and particularly biodeposits, is a well-established component of legal frameworks for finfish aquaculture. While the overall objective of laws and regulations is to prevent unacceptable damage to the marine environment from farm wastes, the precise definition of regulatory objectives varies in the legislative instruments of the contributing ICES members. These legislative instruments can be aquaculture-specific (e.g. Norway, Ireland) or may be more general legislation addressing the protection of the environment (Denmark, Faroe Islands, China), the protection and use of water resources (US, Portugal, China, UK-Scotland) or fish habitat (Canada) The European Union (EU) Water Framework Directive (2000/60/EC) and, in certain circumstances, the Marine Strategy Framework Directive (2000/60/EC) are also relevant to the regulation of organic waste from aquaculture in EU countries as well as UK and Norway. Additionally, legislation and policies for the protection of particular habitats can also be relevant. This includes the EU Habitats Directive (92/43/EEC) for EU countries as well as UK

ICES members report a range of management tools at the farm level to prevent and mitigate the potential impacts of organic loading from finfish farms. They include proper siting and production limits, best available practices/technologies, and environmental monitoring for compliance with quality standards. Management measures to prevent and mitigate cumulative and far field impacts and impacts at the regional level are less developed.

For further information see: Annex 4.

Site Selection and Production Limits

An application for a new site or an expansion of an existing site is usually reviewed by one or more responsible agencies to assess the risks of the proposed operations to the marine environment, including the risks of organic waste, as part of the licencing/permitting process (see, for example, Canada's pathways of effects process in Canada Country Report). This assessment can be part of an environmental impact assessment (EIA) (e.g. China, Portugal, UK). In some countries, the applicable legislation requires a special permit or certificate for discharges into coastal or marine environments. For example, Scotland (UK) requires a permit under the *Water Environment Controlled Activities (Scotland) Regulations 2011* (CAR permit). Faroe Islands requires an environmental certificate under the Environmental Protection Act Løgtingslóg nr 134 frá 29. Oktober 1988. The US. requires a National Pollutant Discharge Elimination System (NPDES) permit under s. 404 of the federal *Clean Water Act*, which can be issued by the Environmental Protection Agency (EPA) or states authorized by EPA.

The risk of bio-deposition is assessed based on pre-investigations (baseline surveys) and expected impacts. The use of predictive depositional models can be a regulatory requirement for marine finfish applications (e.g. Canada, Norway). Scotland (UK) requires the use of one specific depositional model: new-DEPOMOD (Scottish Government 2019).

The assessment of eutrophication risk from a proposed finfish farm is less frequent in the regulatory regimes. ICES members report gaps in knowledge regarding the contribution of farm-derived nutrients to the nutrient pools and cycling, effects on plankton and macroalgae in the vicinity of the farm, and baseline levels of nutrient in the environment. In the case of Denmark, national and international obligations and recommendations to limit or reduce eutrophication in coastal and marine waters are a crucial consideration in the regulation of organic waste from finfish farms, and the release of nitrogen and phosphorus is considered a limiting factor for industry growth. Denmark uses three-dimensional hydrodynamic models in the EIA to predict the effect of nitrogen and phosphorus release from a finfish farm to support decision-making in issuing an environmental permit. Norway also reports increased use of hydrodynamic and dispersion models to improve site placement with respect to avoiding non-dispersive water bodies or overlapping discharge plumes.

Baseline surveys and model results are used to support one or more of the following siting and licensing/permit decisions by the responsible authorities:

- **Assess the suitability of a proposed site or expansion of an existing site**. Desirable site characteristics tend to revolve around depth, current speeds (waste dispersion capabilities), suitable wave climate, benthic characteristics and avoidance of sensitive or ecological valuable species.

- **Assess potential negative effects of farm discharges on protected areas and other sensitive, vulnerable, or critical areas or features**. For example, Canada reports that the siting assessment seeks to avoid locating farms over or near sensitive habitats. US also reports preventive measures to protect sensitive habitat at the licensing/permitting stage.

In Norway, the authorities may require a nature type mapping of the proposed finfish farm area or area expansion to avoid impact on sensitive habitat (for example, several protected coral reefs) as part of the mandatory environmental pre-investigations required by Norwegian Standard 9410:2016. There is currently no standardized guidelines or thresholds set for such investigations.

In all EU-countries and UK, all applications for new farms or changes to existing farms (new locations, enlargements etc.) must undergo a habitat assessment under the EU Habitats Directive if the farm is situated in, nearby or can harm a designated area or species. A new or amended licence can only be issued after having ascertained that it will not adversely affect the integrity of the site or species concerned.

China's legal framework also consider the protection of aquatic species and their living environment and the establishment of aquatic species protection zones in the main areas where aquatic species of high economic and hereditary breeding value grow and propagate. No unit or individual may engage in fishing in the protection zones without the approval of the administrative department for fisheries under the State Council.

ICES members note that guidelines to prevent or mitigate negative impacts to sensitive areas or species are limited and that there is a lack of detailed conservation objectives as well as gaps in the scientific knowledge of tolerance limits of sensitive habitats.

- **Production limits for each farm**. Licenses/permits limit the allowed production at any given site to ensure that organic waste can be assimilated by the environment. The production limits can be stated as maximum biomass, production quota, stocking density, or maximum feed quota for the site. For example, Scotland adopts a biomass limit but is considering replacing this parameter with a maximum feed allowance per site (SEPA 2019). It is also worth noting that Scotland's regulatory framework had traditionally capped the biomass of each site at 2,500t to prevent environmental impact. The new regulatory framework has eliminated this precautionary limit (SEPA 2019).

- **The identification and delineation of the allowable zone of effects or "mixing zone"**. For example, Scotland's SEPA states that "on the seabed immediately around fish farm pens, there is a zone in which wastes are not fully mixed and dispersed in the surrounding sea. Under the regulatory framework, we will limit the maximum scale of this mixing zone […]. The mixing zone is defined as an area equivalent to that lying within 100 metres of the pens in all directions. However, the shape of the zone does not have to be symmetrical. […] Fish farm operators will have to manage their sites so that there is no significant adverse impact on the biodiversity of sea life beyond the edge of the mixing zone" (Scotland Scottish Government, 2019.).

Ireland, in turn, also considers an Allowable Zone of Effect (AZE) that will be determined on a site-by-site basis and will take into consideration the direction and strength of the residual flow and any modelling information available for the site in question. The exact extent of the AZE will be determined by consultation between the producer, the Department of Agriculture Fisheries and Food and the Marine Institute (Ireland, Country Report, Appendix 1).

Norway also distinguishes different zones for the regulation of organic waste. The 'local impact zone' is the area under and near a fish farm where most of the larger particles are deposited, normally not extending beyond 15 m from the fish farm. The 'intermediate farm zone' is the area beyond the local impact zone where sedimentation of smaller particles occurs. The regional impact zone is the area beyond the intermediate farm zone. The different zones are affected to different degrees by the organic waste from an aquaculture farm, and therefore are subject to different environmental quality standards (see Monitoring below).

- **The identification of farm-specific monitoring locations** (see Monitoring below).

Best management practices/ best available technologies

In addition to siting decisions and production limits, US and Denmark report the mandatory use of best management practices (BMP) or best available technologies (BAT) to mitigate risk of organic waste. In the case of US, EPA has developed effluent limitation guidelines (ELG) for the concentrated aquatic animal production point source category. Marine Net Pen Facilities producing 100,000 pounds or more of aquatic animals per year must develop and maintain a BMP plan describing how they will achieve narrative requirements regarding, among other issues, feed efficiency, training, and record keeping (EPA, 2006).

Denmark considers a mandatory BAT description in the environmental permit. The farmer must submit a written statement describing improvement in BAT before each production cycle.

Monitoring

Sediment Monitoring

Benthic monitoring to demonstrate compliance with sediment environmental quality standards (EQS) is another key regulatory tool reported by ICES members. Some ICES countries have a self-monitoring system. It is the farm operator's responsibility to undertake monitoring according to monitoring protocols or standards and/or specific conditions of its licence/permit and to submit those monitoring results to the responsible authorities. This is often conducted by consulting companies and results are subject to audits by responsible agencies (e.g. Norway, UK - Scotland, Canada). In other cases, monitoring is undertaken by independent third parties (e.g. US (Washington), Denmark, Ireland) and can also be subject to audit (e.g. Ireland).

Monitoring requirements are included either in a generally applicable standard (e.g. Canada, federal Aquaculture Activities Regulations (SOR/2015-177) and Monitoring Standard (2018); Norway NS 9410:2016) or in each particular license/permit (e.g. Denmark). In both cases, a risk and evidence-based approach (considering for example farm size, location, hydrographic conditions, etc.) can be adopted to determine the monitoring frequency, measured indicators, or number or location of sampling stations.

Sediment monitoring is required below, at the edge or in close proximity of the cages or containment array. Additional monitoring can be required at reference points or control stations (e.g. Denmark), at a distance from the cages (e.g. Canada-B.C.), or at the edge of an allowable zone of effects, mixing zone, or intermediate impact zone (e.g. Scotland, Norway, Ireland). The precise location of monitoring stations can be defined in the monitoring protocol based on criteria such as distance to cages or can be a farm-specific monitoring plan included in the license/permit to reflect particular circumstances of the site. The monitoring frequency is, at a minimum, once during each production cycle, at or near peak biomass. However, ICES members also report annual monitoring (e.g. Ireland, Denmark) or more frequent monitoring based on monitoring results (e.g. Norway B-Investigations, Faroe Islands).

Selected examples of monitoring protocols are included here (see Appendix 1 for more information):

- Norway requires environmental monitoring to be conducted both under and close to the farm (the local impact zone) and away from the farm (intermediate impact zone). B-investigations target the local impact zone and utilize a pH/Eh index and a range of sensory parameters. C-investigations are conducted (less frequently) to assess the outer zone of effect using more detailed benthic indicators (including macrofauna). There are established thresholds for different impact levels (4) associated with increasingly severe management responses (frequency of sampling) employed in response to increases in environmental impacts. If the level of impact exceeds level 3 the authorities decide on mitigating actions.

- Maine (US). The Department of Environmental Protection (DEP) requires monitoring of sulphide at 35 meters a minimum of once per growing cycle. If sulphide is above a set level, monitoring for benthic infauna are required when maximum biomass for the facility occurs.
- Washington (US.). The Department of Ecology (ECOLOGY) manages Section 402 NPDES permits that require sediment monitoring of benthic impacts around a 100-foot perimeter from the farm sites. Impact limits are set for the organic enrichment of sediments to distinct threshold values. The Section 402 NPDES permit requires that a sampling plan complying with specific permit requirements be developed, including a sediment monitoring cycle to be carried out by a third-party consultant.
- Canada (B.C.): samples of the benthic substrate are collected at a minimum of two sampling stations (30 m and 125 m away from the cage edge) along two transects that align with the area of greatest predicted impact and with the dominant and sub-dominant current directions. If the containment array is greater than 200m in length and its long axis is perpendicular to the direction of the dominant current, additional sampling is required. In hard bottom sites, visual monitoring is required. Images must be recorded along two transects that start at the edge of the proposed containment array, align with the area of greatest predicted impact and with the dominant and sub-dominant current directions and extend for a minimum of 140 m, with a maximum deviation of ± 20% from that bearing. Sampling is not required within areas where depths exceed 300 m (Aquaculture Activities Regulation Monitoring Standard, 2018).

A variety of indicators are used to assess benthic conditions, often in combination. In some cases, the indicators used to assess the local impact zone are different from the (more sensitive) ones used to assess the intermediate impact zone (e.g. Norway, Scotland). Ireland's regulatory system considers a Type I and Type II monitoring. The more complex Type II monitoring is required for farms that have higher risk of deposition based on production tonnage and mean current speeds (Department of Agriculture, Fisheries and Food (Ireland) 2008: 2).

In the case of soft sediments, indicators used to assess organic enrichment include:

- US (Maine) - Canada: free sulphide
- Ireland: a combination of Redox potential, organic carbon, and visual examination (type I monitoring) as well as biological examinations (type II monitoring)
- Norway (local impact zone): a combination of chemical indicators (pH and Eh) and a range of sensory parameters (presence/absence of infauna, and qualitative assessment of sediment including presence of gas bubbles, odour, consistency, colour, grab volume, and thickness of deposited sludge).
- Norway (edge of intermediate impact zone): macrofauna diversity and sensitivity indicators. In this case, the composition and abundance of benthic invertebrate fauna needs to demonstrate good ecological status as defined in the regulations implementing the EU Water Framework Directive.
- Faroe Islands: follows the Norwegian standard for the local impact zone but includes organic carbon measurements.
- Scotland (edge of cage): the abundance of re-worker polychaete worms.
- Scotland (mixing zone): macrofauna diversity and sensitivity indicators (IQI).
- Denmark: nitrogen, phosphorus, Redox. Visual monitoring is required mid-cycle.
- Portugal (monitoring of environmental parameters recommended for offshore aquaculture): granulometry of superficial sediments, sediment organic content, source of organic matter, benthic macroinvertebrates (composition, abundance and biomass), specific composition, structure, density, biomass, trace metals, residence time and demographic aspects of the ichthyological communities.

ICES members stated that EQS for hard bottom are still under development (e.g. Scotland, Norway). Norway, for example, has performed alternative surveys at hard bottom sites, which are defined by the responsible authorities. In 2018 some basic guidance was provided on how to conduct hard bottom monitoring, considering standardizing the quality, type and number of images collected, which is currently under revision. Canada's regulatory framework assesses benthic deposition on hard bottom based on presence of Beggiatoa, opportunistic polychaete complexes or barren substrate. The specific procedures for visual monitoring are included in the Aquaculture Activities Regulations' Monitoring Standard (2018). Work is also underway to develop a method for assessing impacts using the microbial communities that inhabit the flocculent material that overlies hard rock (Keeley *et al.* In Review)

Regulations do not consider specific monitoring requirements or standards for sensitive habitats. Some ICES member report that monitoring requirements for sensitive habitats can be established through licence/permit conditions (i.e. Ireland, Scotland, US). Additionally, monitoring programs for conservation features can be implemented by responsible authorities (e.g. Ireland, China).

China and Norway report that additional and complementary benthic monitoring also occurs as part of research projects or initiatives. For example, the recent (2017) BluePlanet initiative considers more detailed monitoring programs for water quality, sediment conditions and macroalgae habitat in three southern regions in Norway.

<u>Water column monitoring</u>

Only some contributing ICES members reported water column monitoring as a mandatory requirement for farm operators (Ireland, US). Ireland requires nutrient monitoring surveys to be carried out monthly during December-March, including ammonia, nitrite, nitrate and phosphate, water temperature and salinity (Monitoring Protocol Nr. 2 for offshore Finfish Farms: Water column monitoring (2001)). Maine (US), in turn, requires the establishment of a Water Column Mixing Zone, defined as the area within and extending 30 meters beyond the perimeter of a net pen in all directions on the surface, and down to the seabed/water column interface. The dissolved oxygen concentration within the water column mixing zone must not be lower than 6 mg/L at any point from the surface down to the seabed/water column interface. The Department of Environmental Protection reserves the right to require routine or periodic dissolved oxygen monitoring. Other water quality parameters within the water column mixing zone must comply with the Standards for classification of marine and estuarine waters, 38 M.R.S.A. § 465-B.

Other ICES members report that water column monitoring can be included as a licence/permit condition. In the case of Denmark, the monitoring plan in an environmental permit will normally consider salinity, temperature and O_2 samples taken on daily or weekly basis. Portugal's recommended monitoring of environmental quality parameters for offshore aquaculture considers salinity, temperature, transparency, turbidity, oxygen, nutrients (nitrate, nitrite, ammonia, phosphate, silica), chlorophyll, phaeopigments, phytoplankton, and aquatic flora.

Water column monitoring programs are also performed by responsible authorities or through industry initiated and financed programs. Norway reports that long-term (2013-) trend monitoring of water quality in coastal waters is regularly performed at 140 stations along the Norwegian coast. Biological (phytoplankton biomass, seaweed composition and infauna in soft sediment) as well as physical support-parameters is measured according to guidelines following the EU Water Framework Directive (Økokyst, Monitoring programme under the Norwegian Environment Agency). Additionally, as part of the Blue Planet initiative, a more extensive sampling program is undertaken following the same guidelines in areas with especially high fish-farm density and total production

The latter program is initiated and financed by the farming companies in the area. Furthermore, biomass and composition of phytoplankton in coastal waters is frequently monitored on a large number of stations to be able to warn the public and industry about toxic species and harmful algal bloom. China, in turn, reports that some research projects include water quality survey and long-term monitoring of aquaculture areas.

Water column monitoring is also performed by farm operators for private purposes including certification (e.g. ASC).

Remedial action

In cases where acceptability thresholds are reached, the operator and the authorities determine mitigation actions to reduce the impacts of organic loading. For example, if the benthic impact of a site in Norway exceeds level 3, the competent authorities decide on mitigation actions. Ireland, in turn, requires the submission of a Benthic Amelioration Plan (Department of Agriculture, Fisheries and Food (Ireland) 2008: 7).

Examples of remedial action include: undertaking good, high-resolution depositional modelling to predict extent of footprint; conducting benthic investigations at a higher frequency; farm repositioning; feed waste control plans; production reductions; and site fallowing (Annex 4).

Other contributing ICES members reported mandatory fallowing for sites that exceed the thresholds of acceptable impact (e.g. Canada, under the federal *Aquaculture Activities Regulation*; US-Washington). Sites can only be restocked when further monitoring demonstrates that the sediment has recovered.

Portugal and China also report regulations addressing financial or legal liability deriving from ecological damage. For example, Portugal requires aquaculture title holders to post and maintain security deposits to guarantee the good environmental condition of the environment and water bodies. China reports that damage to the ecological environment of the fishery waters or fishery pollution is investigated for legal liability.

Cumulative, far-field, and regional impacts

A limited number of contributing ICES members report initiatives that address cumulative, far-field or regional impacts.

Marine Scotland has developed locational guidelines, which classify each Scottish loch based on predictive models to estimate environmental sensitivity using nutrient enhancement and benthic impact indicators (Gillibrand *et al.,* 2019). Lochs are classified as category 1 (Fish farm development would only acceptable under extreme circumstances; must demonstrate no significant adverse environmental effects), category 2 (Prospects for further fish farm development limited; potential for expansion of existing sites; potential increase of biomass/production calculated through capacity models) or category 3 (Areas where there are better prospects of satisfying environmental requirements). The locational guidelines are used by local authorities for the development of aquaculture planning frameworks and for informing decisions on development permits, on the advice of Marine Scotland.

Far-field effects can be considered during the site-specific assessment of a finfish farm license/permit and benthic monitoring procedures. Under the new regulatory framework, Scotland requires farm operators to demonstrate, and then manage their sites, to ensure that any accumulation in the wider marine environment is sufficiently limited to prevent it from having a significant adverse impact on biodiversity of sea life (SEPA 2019). In Norway, C-Investigations consider monitoring in the deepest part of the outer zone of effects, often removed from the local production area. At steeply sloping sites, samples must be taken from the bottom of the slope. Effects are therefore tracked through time and subject to quantitative assessment (NS 9410:2016).

Spatial planning (e.g. China) and distances between farms (e.g. Canada) are also tools that can mitigate cumulative impacts from organic waste in finfish farm areas. Canada further reports initiating off-lease monitoring to understand the scale and persistence of far-field organic loading from finfish farms.

Sensitive Areas

Potential negative effects of farm discharges on protected areas and other sensitive, vulnerable or critical areas or features are considered at the planning stage (e.g. Scotland) and during the application process for a new or amended farm licence/permit (e.g. Canada, Scotland, Norway, US, all EU-countries). In EU-countries, all applications for new farms or changes to existing farms (new locations, enlargements etc.) must undergo a habitat assessment under the EU Habitats Directive if the farm is situated in, nearby or can harm a designated area or species. A new or amended licence can only be issued after having ascertained that it will not adversely affect the integrity of the site or species concerned.

Some contributing ICES-members report that guidelines to prevent or mitigate negative impacts to sensitive areas or species are limited, which may result from both lack of detail conservation objectives and lack of scientific knowledge of tolerance limits of sensitive habitats.

Specific monitoring requirements for sensitive habitats are not considered in regulations. Licence conditions may establish monitoring requirements for sensitive habitats (i.e. Ireland, Scotland, US). Additionally, monitoring programs for conservation features are implemented by responsible authorities (e.g. Ireland, China).

3.1.2.4 Emerging issues and knowledge gaps with organic waste

In general, the ecological effects that manifest in the soft sediment habitats that exist beneath the majority of fish farms are well understood and able to be measured and regulated. However, the way farming is conducted is evolving this brings about a range of new potential issues and areas of uncertainty.

Regional effects

Trends toward highly dispersive sites creates uncertainty around the spatial extent of effects (e.g., Keeley *et al.,* 2019) and demands a greater understanding of particle movement including resolving the complex process of particle resuspension (Carvajalino-Fernández *et al.*, 2020). There is also greater potential for regional effects which are difficult to regulate.

Hard bottom habitats and sensitive species

High current sites are often in close proximity to hard-bottom habitats which are colonized by species that are poorly understood in terms of their tolerance to waste or their recolonization ability should they be displaced. There is also greater probability of overlap with habitats containing sensitive species. In general, however, the trend towards dispersive sites should have a mitigative effect with respect to ecological effects from organic waste.

Hard bottom standards

Contributing ICES countries report lack of standards for hard-bottom habitats and incomplete understanding of the effects of organic waste on non-soft sediment benthic habitats. Norway is in the process of producing a guidance document for sampling on mixed- and hard-bottom habitats, based around visual tools and qualitative assessments. Advancements have also been made in to using special sampling devices and microbial eDNA to quantity effects on hard bottom habitats.

Uncertainty with more exposed / novel environments

Larger, open ocean instalments change both the intensity of fish culture (and therefore waste output) and the physical exposure of the site which impacts waste dispersion. Deeper, more open ocean sites may also encroach on new habitats that have not been the focus of aquaculture and environmental interactions studies to date. Similarly, the development of large mobile inshore / offshore farming structures will disperse waste differently (being mobile), and over habitats that would not normally be exposed to such elevated levels of biodeposits.

Contribution of farms-derived nutrients to eutrophication

Norway: Increased use of hydrodynamic and dispersion models to improve site placement with respect to avoiding non-dispersive water bodies or overlapping discharge plumes.

Canada (and similarly China): contribution of farm-derived nutrients to nutrient pools and cycling, including potential contribution to eutrophication, unknown.

Selection of appropriate indicators (reliable, cost-effective, quick)

Contributing ICES countries report ongoing work to validate new methods for measuring organic enrichment impacts, either directly (biological) or using proxies (chemical or remote methods), as well as determination of thresholds that are equivalent to existing regulatory thresholds (Canada). In Canada, there is ongoing research evaluating other measures of organic enrichment using new technologies and alternative metrics for measuring sulphides. Researchers in Canada, New Zealand, Switzerland and Norway in particular, are rapidly advance knowledge around eDNA-based methods for benthic enrichment monitoring.

Alternative mitigation measures

Contributing ICES countries identified a number of measures that could contribute to mitigate negative impacts of organic waste form finfish farms, for which there is currently insufficient knowledge and/or economic feasibility. These include:

- Close containment (Several new initiatives)
- IMTA especially mussel production has the potential to mitigate water column enrichment, but the effectiveness it yet to be properly demonstrated and is not currently in use (except China reports integrated aquaculture).

3.1.3 Contaminants and therapeutants

There are number of chemicals in use for treating farmed salmon for bacterial diseases (antibacterial agents), intestinal parasites and salmon lice, as well as sedative and anesthetic agents used for vaccination and transport. These chemicals can enter the marine environment directly from fish farms or from well-boats. In addition, there are chemicals used to prevent fouling on aquaculture structures. Anti-sea lice drugs or therapeutants are administrated either as a bath treatment or added to the salmon feed (in-feed). In most cases, chemical use is closely regulated, for example, in Norway, the total annual consumption of each of the therapeutants is provided by the Norwegian Institute of Public Health (**https://www.fhi.no/en/**). In addition, the public **www.Barentshwatch.no** publishes the use of anti-sea lice treatment, either therapeutants, mechanical or biological, for each farm on a weekly basis. Effects of delousing agents on species other than the target species, i.e. non-target, is linked with the species sensitivity and the delousing agent's presence in the environment. Presence in the environment is affected by the consumption, the dispersion and dilution for drugs used as bath treatment and for the in-feed drugs, the decomposition/persistence in the sediment. Wind and currents will determine the speed at which they disperse and become diluted, but the rate of decomposition/persistence will also determine the impact and how quickly concentrations will be reduced in the environment. The weighting of the impact factors differs depending on whether the delousing agents are given as bath treatment or in-feed.

When assessing potential impact on non-target species it is also necessary to consider variations in the species diversity and occurrence. E.g. species diversity will change naturally over the course of a year and there are species which exist only in some geographical areas, and some life stages that occur only at certain times of the year. There is also substantial variation between species that live in free water masses and those that live on the seabed. In addition, species diversity will vary between hard- and soft-bottom habitat. Bath treatments will mainly affect other species that live in the free water masses. Copepod and free-swimming larval stages of various crustaceans are particularly vulnerable. There is less likelihood that species living in deeper water will become exposed to bathing agents. Wind and current conditions determine whether species along the shoreline will become exposed. In-feed drugs will mainly affect species living on the seabed. Non-target species will be able to absorb the therapeutants through waste feed and faeces. Since in-feed therapeutants containing diflubenzuron and teflubenzuron affect chitin synthesis, species with exoskeleton or similar structures containing chitin will be particularly vulnerable.

3.1.3.1 Therapeutants as bath-treatments

Cause

Therapeutants given as bath treatment include the active ingredient hydrogen peroxide, azamethiphos, cypermethrin (use discontinued in some countries, e.g. Norway) or deltamethrin. The treatment is applied either in the pens or in well-boats. When treatment takes place inside the pens, the therapeutants are released directly into the surrounding environment, whereas, when treatment takes place in well-boats, the therapeutants are released into to the sea while the boat is in motion, i.e. often some distance from the farm. The dispersion and dilution of therapeutants following a bath treatment will vary both between sites and at the same site. This is influenced by fluctuating hydrographic conditions such as current, waves, temperature and water stratification at the discharge point. Following release, the drugs are most likely to remain in the upper water layers. The vertical transport of water to deeper layers e.g. in a fjord, is rare, but when the water column is well mixed – which is more common in winter – a mixture containing hydrogen peroxide can sink to the bottom. Emissions from a farm will disperse with the current and simultaneously mix with surrounding water, causing them to dilute over time to concentrations that will not affect non-target species. The range of dispersion and speed of dilution are particularly dependent upon the currents at the discharge point.

Effects

There are potential effects from the released therapeutant 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 There is less probability that species living in deeper water can be exposed to the therapeutants. Considerable research has been completed on the toxicity of commonly used sea lice therapeutants (see e.g. Refseth *et al.* 2017, Urbina *et al.* 2019, Parsons *et al.* 2020, and references therein). In conclusion, therapeutants used against sea lice have detrimental effects on a number of non-target species, but the effect depends on the agent as well as the species. Azamethiphos is perhaps less harmful compared to e.g. hydrogen peroxide and deltamethrin. The effects are also highly species-specific and even stage specific, so any risk assessment must be carried out with local fauna.

Parsons *et al.* (2020) used a hydrodynamic model to simulate dispersal of deltamethrin and azamethiphos into the marine environment around selected Norwegian farms. They estimated the potential impact zone for European lobster larvae (*Homarus gammarus*) by taking into account their sensitivity toward the therapeutants. As azamethiphos was less toxic, the impact area was small, typically 0.04 to 0.2 km^2 while the deltamethrin could impact from 21.1 to 39.0 km^2.

The half-life for deltamethrin in marine sediments has been estimated at approximately 140 days, indicating that multiple treatments may result in accumulation of this compound in sediments near cage sites (Gross *et al.*, 2008). Synthetic pyrethroids, such as cypermethrin and deltamethrin, are unlikely to accumulate to a significant degree in fish and aquatic food chains since they are rapidly metabolized (Kahn, 1983). However, they have a low water solubility (Tomlin, 1994) suggesting that they may persist in sediment for weeks or months and therefore also have the potential to effect benthic organisms, but this is yet to be proven.

Sea lice related chemicals are also a species and site- /region-specific problem and therefore is an issue that will vary greatly in relevance. For example, sealice cannot reproduce at salinities under 20-25 PPT, so are not a problem for trout farming in the Baltic due to lower salinity. Additionally, King and Pacific salmon farms in the southern hemisphere (Tasmania and New Zealand) have encountered little to no sealice problems and do not use any of these treatments.

3.1.3.2 Therapeutants as in-feed-treatments

Cause

Therapeutants given as in-feed treatment include the active agent diflubenzuron, teflubenzuron and emamectin. Most of the in-feed therapeutants will be bound to organic matter such as uneaten medicated pellets and faeces, which spread to the environment via waste feed and faeces. Bound to organic particles they are relatively stable and residual concentrations can be found in the bottom sediment several months after treatment. Large faecal particles and pellets will be deposited on the seabed in the vicinity of the farm, while smaller particles will spread further away depending on the water current at the farm. Most of the drugs are found beneath or near to the farm to 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.

Effects

The species most likely to be affected by in feed agents are those closely associated with the sediment as all three agents have low water solubility and a high potential to be adsorbed onto and bound to suspended particulate material. The agents will persist in the sediments for a considerable period of time having half-lives of approximately 100 to 175 days. Benthic communities in the organically enriched sediments below fish farm are generally dominated by small worms, which play a vital role in remineralising waste products. Although numerous benthic assessments have been conducted around fish farms, it is difficult to separate these effects from that of organic enrichment per se. Dedicated studies on the effects of emamectin benzoate and teflubenzuron on infaunal polychaetes indicated that predicted sediment concentrations are unlikely to adversely affect polychaete communities below fish farms (Telfer *et al.*, 2006, Fang *et al*. 2020).

A recent study by Wilding *et al.* (2017) based on a meta-analysis of long-term data in Scotland suggests that there are possible effects of emamectin benzoate on crustacean communities at distances up to 1 km from the fish farm. This study led to a revision of the sediment EQS for emamectin benzoate in Scotland (WRc, 2017. Emamectin benzoate water column concentrations are expected to be considerably lower than sediment concentrations and are unlikely to pose a risk to planktonic organisms. Results from laboratory toxicity tests support this conclusion, with acute toxicity values orders of magnitude higher than the maximum allowable water concentration in Scotland of 0.22 ng L^{-1}. A recent study in Shetland showed that after continuous use of emamectin it was found in 97% of samples (with a detection limit 0.0034 µg/kg dry weight) (Bloodworth *et al.*, 2019).

Planktonic organisms can be exposed to flubenzurones through water and particulate matter during and immediately after medication. The effect of flubenzurones in the aqueous phase has been studied in some marine species, including larvae of northern shrimp (*Pandalus borealis*) (Bechmann *et al.* 2018). In general, the LC_{50} value is higher than the highest concentration of 295 ng/L, which has been measured in the aqueous fraction in connection with flubenzuron use. Flubenzurone doses similar to those given to salmon over a 7- or 14-day period resulted in mortality in European lobster juveniles (*Homarus gammarus*) and the pink shrimp (*Pandalus montagui*) (< 73% mortality) (Samuelsen *et al.* 2014, 2020, unpulished data). Dose response curves based on measured concentrations of teflubenzuron within the shrimp were used to calculate a series of lethal threshold concentrations (Samuelsen *et al.*, 2020). The LC_5, LC_{50} and LC_{90} concentrations of teflubenzuron causing low, median and high levels of mortality in rockpool shrimp were estimated to be 1.2, 18.4 and 150.6 ng g^{-1}, respectively. These concentrations are similar to those reported in wild crustacean species, including shrimp species in the vicinity of Norwegian fish farms, both during and after teflubenzuron medication, suggesting that exposure to low doses of this compound can pose a significant risk to wild shrimp populations.

3.1.3.3 Regulation of contaminants and therapeutants

Different contaminants and therapeutants are as described above used in open-cage aquaculture as antifouling, feed-ingredients, treatment for parasites, disease treatments etc. These chemicals or decomposition products can be dispersed and diluted in the water column, may bind to suspended solids and subsequently settle to the seabed, or if bound to uneaten feed or faeces, settle directly to the seabed, where there is the possibility of accumulation in the sediment. As therapeutants are designed to be toxic to specific types of organisms, the persistence and accumulation of these compounds in the marine environment can result in negative impacts on wild non-target species. Similarly, the accumulation of contaminants can also result in negative ecosystem impacts.

The use of chemicals is often regulated as part of a fish farm environmental license or permit. For the EU member states, the allowed outlet concentration of chemicals is regulated by the Water Framework Directive and implemented in the member states by setting water quality criteria and standards. Further EU-regulation requires an Environmental Impact Assessment and, if there are any vulnerable habitats that can be affected, a habitat assessment is required under the Habitats Directive.

Fish health related chemicals (drugs, pesticides, antibiotics) generally need to be approved by the competent authorities and prescribed by licensed veterinarians. The choice of chemicals treatments or therapeutants varies by jurisdiction as drug and pesticide approval processes differ. Product-specific restrictions can be included as part of the regulatory approval. For example, in Canada, the use of some sea lice treatments is restricted for sites that are in shallow waters to protect the benthic ecosystem. Further, the regulations can consider restrictions on the number of treatments with one product per year or per production cycle. The effect and concentration in the water column and the sediment can be predicted using hydrodynamic models, to help inform risk-based approaches for the use of therapeutants.

The presence of chemical in the sediments can be included in the sediment monitoring programs (e.g. Denmark, USA and Norway). For example, in Norway, the fish farmers are required to monitor copper and zinc levels in the sediments close to the fish farm pens every second or third cycle of production. High levels in the sediments may lead to decisions to prohibit it's use as an antifoulant at the given locality. In other countries, the requirement to monitor chemicals in the sediment can be included as a licence/permit condition (Ireland) or can be undertaken directly by the competent authorities (e.g. Canada). One challenge of a monitoring program is that the concentration in the water column and in the sediment for the used contaminants and therapeutants often can be lower than the detection limit, which is why modelling may be used instead

3.1.3.4 Knowledge gaps

There is a lack of comprehensive information on the effects of organic contaminants from both marine and terrestrial feed sources on different marine organisms and life stages.

The effect of effluents on non-soft-sediment benthic habitats (and species) is not well understood, which is reflected in the differences in monitoring and compliance thresholds for aquaculture impacts on hard-bottom habitats.

There is a lack of historical long-term regional data and poor comprehension of what constitutes pristine baseline conditions.

For therapeutants, there are significant knowledge gaps related to: their persistence in the marine environment; the effects of long-term or multiple exposures during the life cycle of non-target species; and the effects of exposure to multiple medicines on non-target species and the ecosystem.

3.1.3.5 Emerging issues

Bioremediation of existing sites.

New production systems, like closed-containment systems.

3.1.4 References

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3.2 Parasite and pathogen transfer

3.2.1 Background and structure

3.2.1.1 Parasite and pathogen transfer from marine finfish aquaculture to wild fish

Notwithstanding good husbandry, biosecurity and biocontainment practices, cultured finfish do become infected with infectious agents that they are exposed to in the marine environment. A number of pathogens and parasites can occasionally become abundant in aquaculture farms representing a risk of transfer to wild fish (i.e., spillback).

The ICES Working Group on Pathogens and Disease of Marine Organisms (WGPDMO) annually publishes a summary of new and emerging disease trends in wild and cultured fish, molluscs and crustaceans by ICES country members (see ICES, 2019 section 4 for details).

3.2.1.2 Division of issues and knowledge gaps

The issues and knowledge gaps are divided below into parasites and pathogens (viruses and bacteria). While there are a number of emerging parasitic infections on farmed finfish that have been reported through the WGPDMO (i.e., *Paramoeba peruans* (amoebic gill disease, complex gill disease (CGD), and *Ichthyobodo* spp. ("costia"), ICES, 2019), the focus of this report for parasites is on sea (or salmon) lice, *Lepeophtheirus salmonis*. This is because the knowledge of salmon lice transmission from farmed to wild fish is more developed than for other parasites or pathogens, and sea lice can have additional bespoke legislation.

3.2.2 Parasites

3.2.2.1 Description of the cause

The salmon louse *Lepeophtheirus salmonis* is the most abundant parasite that affects farmed Atlantic salmon in the ICES salmon producing countries (Costello, 2009), and is therefore the focus of this overview. 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). 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.*, 2018).

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. The duration of the first two nauplii stages is typically 40-50 degree days (the product of number of days and temperature), i.e. 4-5 days for water temperature of 10 ^{o}C. The third copepodite stage lasts typically until 150-170degree days (Johnsen and Albright, 1991; Samsing *et al.*, 2016; Hamre *et al.*, 2019). Thus, the duration of the free drifting period is from almost a month in relatively cold winter water temperature (~5 ^{o}C) to 1-2 weeks in relatively warm summer water (~16 ^{o}C).

The planktonic salmon lice stages avoid low salinity water (Crosbie *et al.*, 2019). This and other biological characteristic have been used in salmon lice dispersion models (Sandvik *et al.*, 2020).

The planktonic copepodites 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.*, 2018). 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.* 2008; Asplin *et al.* 2014; Sandvik *et al.*, 2016;).

Wild salmonids represent a natural infection reservoir for salmon lice. However, the presence of large numbers of farmed fish in an area can substantially increase the infection pressure experienced by these wild populations (reviewed in Heuch *et al.* 2005). 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).

3.2.2.2 Effects on wild fish

The salmon louse can cause harm to its salmonid host (reviewed by Torrissen *et al.*, 2013). Since it feeds on mucus, skin and blood, the fish is exposed to an increased likelihood of infections and, if many lice are present, problems with osmotic regulation (Pike and Wadsworth, 1999). Approximately 0.3 lice per gramme fish is generally regarded as lethal for Atlantic salmon (Taranger *et al.* 2014; Thorstad *et al.* 2015) but this number may vary due to host genetics (Lush *et al.*, 2019) and behaviour. Out-migrating wild 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). Preliminary studies in New Brunswick, Canada, indicate that the duration of migration through areas with farms is in the order of days. When other salmonids (e.g. sea trout and Arctic char) reside in the fjords and coastal waters where salmon farms are located, these species have 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). Negative effects associated with sea lice have also been reported in Scotland (e.g. Shepard *et al.*, 2016; Susdorf *et al.*, 2018) and Ireland (e.g. Gargan *et al.*, 2012; Gargan *et al.*, 2016; Shepard and Gargan 2017). Canada has a more dispersed farmed salmon industry compared to those in Europe, but modelling studies have investigated the role of sea lice infestations on farms that have also suggested negative effects on wild populations (Jones and Hargreaves, 2009; Krkosek *et al.*, 2011; Krkosek *et al.*, 2013; Groner *et al.*, 2016; Nekouei *et al.*, 2018).

In addition to the direct effect of salmon lice epidemics on wild salmonids, there may be indirect effects on other species in the habitats close to fish farms (Oppedal *et al.*, 2011; Page and Burridge, 2014). To reduce sea lice burdens, farmed fish can be treated therapeutically with various chemical substances, that may enter into the environment surrounding the farm. This represents a potential threat to local species, in particular crustaceans like shrimp (e.g. Parsons *et al.* 2020) and lobster (e.g., Burridge, 2013, Burridge and Van Geest 2014). This is further discussed in section 3.1.3.

3.2.2.3 Legislative and regulatory management of sea lice

The ICES countries Canada, Faroe Islands, Ireland, Norway, UK (Scotland) and USA, all have legislation that can mitigate against the spread of salmon lice from aquaculture. In Denmark, while the farmers monitor for sea lice, there is no legislation surrounding them as they are not considered an issue due to the low salinity of the inner Danish waters. Treatments here are considered not necessary nor are allowed.

In Norway, Canada, USA and Ireland the legislation acts to protect the wild salmonids, but in the Faroe Islands the legislation was originally intended to mitigate the sea lice infection pressure at farms, as the knowledge of wild salmonids was scarce. This is an area of active research to increase knowledge of local sea trout.

In Norway, increase in the commercial production of Atlantic salmon, trout and rainbow-trout is regulated through a "traffic-light system" (Produksjonsområdeforskriften, 2017). The potential effect of salmon lice on wild populations of salmonids (currently only Atlantic salmon is included) is used to regulate production. The coast of Norway is divided into 13 production zones, and within each zone the impact on the wild salmon is assessed through a combination of field-surveillance and modelling of salmon lice dispersion. Based on predefined levels of lice-induced mortality of the populations (%), the production areas are defined as being one of three zones; green (<10%), yellow (10-30%) or red light (> 30%) which in turns give the farmers an opportunity to increase production volume (biomass) by 6% if green and reduce by 6% reduction in red areas. Yellow areas maintain the same production volume.

In the Faroe Islands the sea lice levels plays a role in regulating the size of commercial production. Unlike Norway, the regulation is based on the sea lice infection at the individual farms, and not in regions. Defined thresholds are set for the maximum number of adult female salmon lice at the farms and penalty points are given if the amount of salmon lice exceed the threshold and also for the overuse of sea lice treatments. The total number of penalty points during one farming cycle determines the amount of fish in the next farming cycle.

Most countries have some regional coordination, but the regulation and monitoring are largely based on counting of sea lice levels at the individual farms. Thresholds for the maximum number of adult females per fish are set but do not usually take into account the size of the farm, and therefore the total number of lice that could be released into the environment by multiple sites is not assessed. Norway is currently the exception as the traffic light system is based on lice within hydrodynamic areas. Norway, Canada, Scotland, USA, Ireland and Faroe Islands all have detailed guidelines for monitoring salmon lice on farmed fish, describing the number of fish to be investigated and the frequency of sea lice counting. Treatment thresholds are mostly based on the number of adult females per fish, but in some jurisdictions, the number of preadults is also taken into considerations. Both the thresholds and the requirement for action varies between countries. In some countries, actions are initiated if the numbers are over thresholds and due to logistics, the number of sea lice can be far over the limit before the actions are affected. In the Faroe Islands, the system with the penalty points starts at the first sea lice counts above the threshold and therefore actions are taken before the threshold is reached.

Table 3.2.1. Overview of sea lice management strategy in some ICES countries.

Country	Responsible agency	Regional coordination	Farm level monitoring	Mitigation
Canada	Fisheries and Oceans Canada; Provincial governments	Coordination of farms based on infection connectivity	On-farm sea lice counts. Detailed guidelines	Veterinarian oversight; Thresholds for maximum lice/fish in some regions
Denmark	The Danish Veterinary and Food Administration	No	On-farm sea lice counts by farmers	No treatments necessary
Faroe Islands	Faroese Food and Veterinary Authority	Single fjord management	On-farm sea lice counts. Detailed guidelines	Treatment thresholds, Coordinated production with 2 months fallowing, Imposed emergency slaughter
Ireland	Department of Agriculture food and Marine; The Marine Institute	Single bay management	On-farm sea lice counts. Detailed guidelines	
Norway	Norwegian Food Safety Authority; Norwegian Environment Agency	The Norwegian coast is divided into 13 regions based on infection connectivity	On-farm sea lice counts. Detailed guidelines	Treatment thresholds, Coordinated production with 2 months fallowing, Imposed emergency slaughter
Scotland	Fish Health Inspectorate, Marine Scotland, Scottish Environment Protection Agency	Management areas to allow treatment coordination	On farm sea lice counts. Detailed guidelines.	Treatment thresholds, fallowing, emergency slaughter
USA	U.S. Department of Agriculture, Animal and Plant Health Inspection Service		Integrated Pest Management Plan for sea lice	Seasonal timing of production cycles to avoid coinciding with wild salmon runs

3.2.2.4 Monitoring practices of salmon lice on wild fish populations

Since the salmon louse has a relatively long planktonic period, the potential dispersion from large modern salmon farms which have the requirement for a constant exchange of water, could be substantial. In areas with many farms, the planktonic lice from different farms are assumed to intermix. In addition, the migratory behaviors of wild salmonids are not yet fully understood, thus the assessment of how, where and by how many lice wild fish are infected with is not straightforward. Several methods are used to monitor salmon lice pressure on wild fish.

Observation of infections on wild fish in the field

Wild salmonids are caught with traps, netting and in trawl and the number of lice on the fish is recorded (e.g. Middlemas *et al.*, 2013; Barlaup *et al.*, 2013; Serra-Llinares *et al.*, 2014; Helland *et al.*, 2015; Harvey *et al.*, 2019). While this practice will generate accurate results regarding infestation levels on the individual fish at the time of capture, for jurisdictions with wild salmonid populations that are decline, it may not be appropriate from a conservation perspective due to mortality of the sampled fish.

Observations of infections on fish in sentinel cages

Hatchery-reared salmon smolts are kept in sentinel cages for 1-4 weeks and the number of lice on the fish is counted. The cages are distributed over a larger area to estimate regional distribution of the lice (e.g. Pert *et al.*, 2014; Sandvik *et al.*, 2016). This method determines infection pressure at a specific location, but it does not take into account wild fish behaviours or responses to infection.

Direct observations of lice in the water masses

Measurements that quantify the concentration of the infective copepodites would be of great importance, since this is a direct measure of the infestation pressure. Lice larvae concentrations are higher within a farm site compared with both reference sites and at 100 m distance of the cages, which suggests that a farm can contributes to the ongoing re-infection of the farmed fish (Nelson *et al.* 2017). Off-farm measurement of lice is difficult and labor intensive since the natural abundance of planktonic lice has been found to be patchy and there are many other organisms present making visual identification of the louse hard (e.g. Penston *et al.*, 2004, 2011; á Norði *et al.* 2015, 2016; Skarðhamar *et al.*, 2019).

Numerical modelling using hydrodynamic coupled dispersion models.

Taking into account that knowledge of water currents and the dispersion of lice is important to assess their regional distribution, several coupled dispersion modelling systems have been developed (e.g. Murray and Gillibrand, 2006; Foreman *et al.*, 2012; Asplin *et al.*, 2014; Johnsen *et al.*, 2014; Adams *et al.*, 2016; Samsing *et al.*, 2017; Krangesteen *et al.*, 2018; Myksvoll *et al.*, 2018; Asplin *et al.*, 2020; Cantrell *et al.*, 2020; Rabe *et al.*, 2020). These models have previously assumed that sea lice nauplii and copepodites are passive particles, but they are becoming increasingly sophisticated with the particles possessing more realistic biological behaviours (e.g. Salama *et al.*, 2013; Johnsen *et al.*, 2016; Salama *et al.*, 2017). This mirrors increased knowledge regarding lice biology such as studies that have demonstrated that lice larvae exhibit a diel cycle (Nelson *et al.*, 2017) and are able to move within the water column. Therefore, dispersal modelling is a valuable tool that, as it becomes increasingly refined, requires further experimental studies and validation. Still, a modelling system used in Norway (Asplin *et al.*, 2020; Sandvik, *et al.*, 2020) is sufficiently accurate to discriminate between regions with a high and low infestation pressures (Sandvik *et al.*, 2016; Myksvoll *et al.*, 2018).

Numerical modelling using kernel density spatial interpolation techniques.

This is a simplified method of describing radial distribution of infestation from fish farms based on observed numbers of lice on farmed fish (e.g. Aldrin *et al.*, 2013; Kristoffersen *et al.*, 2014; Salama *et al.*; 2016; Cantrell *et al.*, 2018).

3.2.2.5 Knowledge gaps

There is a substantial body of scientific literature on sea lice and sea lice impacts, but there are still substantial issues and knowledge gaps. The following are some issues/knowledge gaps related sea lice biology, reservoirs, impacts on wild fish, and those related to the management of lice on farms.

Knowledge gaps related to lice biology

- The lice life cycle is affected by temperature and salinity; however, these relationships and biology control mechanisms are likely more complex. Therefore, there is uncertainty as to the likely range of responses by the salmon lice to anticipated effects of climate change, and specifically how this may impact the reproductive cycle, wild host-interactions, etc.

- There have been only limited efforts to characterize the swimming and behaviour of planktonic lice, which indicates that the dispersal and distribution of lice larvae is more complex than hydrodynamic forces. Additional research to further characterize lice movements and behaviours would contribute to improved modelling and the development of management strategies.
- There are also knowledge gaps related to planktonic lice mortality and fecundity.

Knowledge gaps related to impacts on wild fish

- There is a continued need for additional research and empirical data to allow for quantification of population level impacts from exposure of wild salmonids during migration to sea lice on farms.
- There has been research on the response to infestation in juvenile salmonids, and estimation of lethality associated with infestation level and size/age of fish. There have not been similar studies conducted on older salmonids to determine how many lice can an individual fish carry. In addition, studies on wild salmonids are lacking.
- There is few data on the range of secondary population effects of salmon lice infestation (e.g., reduced growth, fecundity).
- There are significant knowledge gaps related to the fate, persistence, and toxicity in the marine environment following use of chemical treatments for sea lice (Section 3.1.3). Additionally, there a knowledge gaps on the population-level effects on non-target organisms (lethal and sublethal impacts).

Knowledge gaps related to management of sea lice on farms (including monitoring)

- While the life cycle of the salmon louse has been characterized, better estimates of the number of salmon louse nauplii produced at farms and behaviours in the sea will improve dispersion modelling predictions
- What are the best practices for designing a regional monitoring system?
- Most jurisdictions employ area-based management for diseases and parasites, which includes the synchronizing of sea lice treatments within a bay, fjord or area. However, these strategies can result in repeated deposit of therapeutants into the marine environment over a short period of time, which has the possibility to overlap and result in impacts on non-target (particularly crustacean) species (Section 3.1.3). Therefore, more research is needed to refine integrated pest management strategies at local and regional areas to both optimize the efficacy of treatments, minimize the likelihood of resistance to the treatments, and minimize the environmental and ecological impacts of the chemical treatments on non-target species.

Many of these knowledge gaps will be best addressed through international collaborative efforts in research, knowledge sharing, and analysis and evaluation.

3.2.3 Viral and bacterial pathogens

3.2.3.1 Description of the Issue

Similar to all food production systems, farmed fish will sometimes become infected with viruses or bacteria that occur in hatchery systems and that are naturally present in the marine environment. The occurrence of viral and bacterial pathogens on farms is region-specific, including which viruses and bacteria are found in different countries and regions within the countries. Additionally, there are strain differences within and between regions which often result in markedly different virulence.

Farmers, fish health experts, including veterinarians, will use their professional judgement in addition to following regulatory or legislative requirements, when determining the appropriate approach to managing or treating an infection and disease.

Prevention and early detection are key elements to minimizing the impact on the farmed fish and on the marine environment, including susceptible wild fish that may be present in the vicinity around an infected farm. If an infection is left untreated, infected fish with clinical signs of disease in aquaculture will shed considerable amounts of pathogens into the marine environment. The result of this additional pathogen burden on wild fish species depends on the complex interaction between host (e.g., species, life stage, genetics, nutrition, fish health/prior exposure, etc.), pathogen (e.g., virulence, survival outside the host, etc.) and environment (e.g., currents, UV, temperature, organic material etc.).

Comprehensive overviews are given annual by the ICES Working Group on Pathogens and Disease of Marine Organisms (WGPDMO. Here we briefly describe effects on wild fish, relevant regulations and knowledge gaps.

3.2.3.2 Effects on wild Fish

Wild fish species may be exposed to pathogens from fish farming 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. Therefore, wild fish may be infected by pathogen prevalent in fish farming at different life stages.

For there to be a risk or an impact on wild fish from infections from fish 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 susceptible wild 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.

The impact of fish farming on wild fish may be assessed by comparing the occurrence of pathogens at different life stages of wild fish captured from different geographical areas with different farming intensities and disease outbreak frequencies. However, pathogen screening data alone as an indicator of infection pressure have limitations (Mcvicar, 1997). Virulent pathogens may cause disease in wild fish, leading to direct mortality or increased susceptibility to predation and therefore rendering them less catchable. Therefore, when screening wild stocks for infections, we are normally able to collect non-diseased infected fish such as individuals that have recently acquired infections or have survived an infection and become “carriers.”

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, and 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, and the vastly different environmental conditions for wild fish compared to farmed fish, including on-farm densities. For example, while molecular techniques allowing to screen for the presence of the genetic signature of infectious agents (e.g., Nekouei *et al.,* 2018) these studies typically do not also include information on the health of the fish sampled (e.g., presence of clinical signs of disease, etc.). Garseth et al. (2013) have shown a lack of a regional pattern in the phylogenetic structure of PRV and attributed this to prolonged and frequent virus exchange between farmed and wild fish. Wallace *et al.* (2017) reviewed wild fish infections around farms in Scotland. There was some evidence of transference but overall, this evidence is difficult to assess as pathogens were also detected from wild fish in areas remote from the farms. However, Madhun *et al*. (2016, 2018 and 2019) have shown no apparent relationship between prevalence of ISAV, PRV and SAV in wild salmonids and fish farming. Screening of escaped farmed salmon have shown that most of fish were infected with one or more viruses prevalent in fish farming suggesting that these escapees could transmit virus to the wild salmonids in rivers (Madhun *et al.,* 2013, 2015).

Given the challenge of directly detecting the impact on wild fish populations from exposure to pathogens from farmed fish, alternative approaches have been used to evaluate this paradigm. For example, in Canada, targeted risk assessments have been conducted to evaluate this question and the scale of the potential impact or consequences. These risk assessments have summarized the critical biological, host, wild fish, and relevant farmed fish management practices, and evaluated the risk at the population level to specific wild fish species for the following pathogens: infectious hematopoietic necrosis virus (IHNV) (Mimeault *et al.,* 2017), piscine orthoreovirus (PRV) (Mimeault *et al,.* 2019), *Aeromonas salmonicida* (Mimeault *et al.*, 2020), *Piscirickettsia salmonis* (Mimeault *et al.,* 2020), *Yersinia ruckeri* (Mimeault *et al,.* 2020), *Renibacterium salmoninarum* (Mimeault *et al.,* 2020), *Tenacibaculum maritimum* (Mimeault *et al.,* 2020), and *Moritella viscosa* (Mimeault *et al.,* 2020).

Another example is the risk assessment of pathogens conducted in Norway since 2011 (Grefsrud *et al.,* 2018)). Until 2018, an expert group assessment of the release, exposure and consequences of infection for the major viral, bacterial and parasitic agents of importance in salmonid farming in Norway were carried out. The assessment evaluated the risk of population effects on three wild salmonids in Norway; salmon, brown trout and artic char. The pathogens evaluated where: Salmonid alphavirus (SAV), Infectious salmon anemia virus (ISAV), Infectious pancreatic necrosis virus (IPNV), Piscine orthoreovirus 1 (PRV1), Piscine myocarditis virus (PMCV), Salmon Gill Poxvirus (SGPV) *Tenacibaculum* spp., *Moritella viscosa*, *Flavobacterium psychrophilum*, *Yersinia ruckeri*, Epiteliocystis (i.e. *Candidatus* Branchiomonas cysticola), *Paramoeba perurans*, *Desmozoon lepophtherii* and *Parvicapsula pseudobranchicola*. Four of the viral agents (SAV, IPNV, PRV1, PMCV) were included in a 2015 review publication describing the Norwegian risk assessment on environmental impacts of aquaculture (Taranger *et al.,* 2015). Alternative risk assessment using Bayesian methodology was implemented in 2019 (Grefsrud *et al.,* 2019), and a new risk assessment for SAV and ISAV on salmon following this methodology will be published in 2021. These two viruses cause notifiable diseases (PD and ISA) and therefore there is a good overview of their occurrence in fish farming. This risk assessment will be based on the available published knowledge and results from surveillance and research programs aimed at assessing virus transfer from farmed to wild salmonids.

3.2.3.3 Legislative and regulatory management of viruses and bacteria

Legislation relevant to the prevention and management of virus and bacteria in farmed fish addresses different objectives: maintaining good farm fish health and fish welfare, preventing the spread of disease to other farms or to wild populations, prevent negative impacts on the environment (including biological and ecological processes), and protecting human health (food safety). This section focuses on regulatory measures to prevent spread of pathogens and parasites to other farms and to the wild. The regulation of environmental impacts of therapeutants has been covered in section 3.1. This ICES Report does not address fish welfare or food safety.

The legal framework for the prevention, detection and control of aquatic animal diseases has a significant level of harmonization among countries resulting from the implementation of international and supranational biosecurity standards, guidelines, and recommendations. All participants are members of the World Organization for Animal Health (OIE) and implement the OIE's *Aquatic Animal Health Code* and the accompanying *Manual of Diagnostic Tests for Aquatic Animals*. The Aquatic Animal Health Code is an international standard for the prevention, detection, and control of significant aquatic animal diseases and for the safe international trade of aquatic animals.[1] The Code contains general (sections 1-7) as well as disease-specific (sections 8-11) guidelines. The general guidelines address: a) notification, diseases listed by the OIE and surveillance; b) import risk analysis; c) quality of aquatic animal health services; d) disease prevention and control; e) trade measures, importation/exportation procedures and health certification; f) antimicrobial use in aquatic animal; and g) welfare of farmed fish.

ICES members that are part of the European Union, as well as UK and Norway, also implement the Council Directive 2006/88/EC on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals. The Directive defines animal health requirements for the placing on the market, importation and transit of aquaculture animals and their products. It also defines the minimum measures to prevent diseases in aquaculture animals and the minimum measures to be taken in response to suspected or established cases of listed diseases in these animals. The EU Council Directive was drafted considering the guidelines and standards of the OIE.

Notifiable diseases under OIE (finfish)	Notifiable diseases under EC (finfish)
Aphanomyces invadans (epizootic ulcerative syndrome)	Epizootic ulcerative syndrome*
Epizootic haematopoietic necrosis virus	
HPR-deleted or HPRO infectious salmon anaemia virus	Epizootic haematopoietic necrosis*
Infectious haematopoietic necrosis	
Koi herpesvirus	Infectious salmon anaemia (ISA)
Spring viraemia of carp virus	
Viral haemorrhagic septicaemia virus	Infectious haematopoietic necrosis (IHN)
Red sea bream iridovirus	Koi herpes virus (KHV)
Salmonid alphavirus	Spring viraemia of carp (SVC)
Gyrodactylus salaris	Viral haemorrhagic septicaemia (VHS)

*Exotic disease

The international standards and European directive are implemented in ICES members and China through legislation and regulations under the responsibility of veterinarian, fish health or food safety authorities. In Canada, provinces (except in B.C.) have day-to-day operational

[1] The OIE is recognized by the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures as the international organization that provides international guidelines, standards, or recommendations in the field of animal health. As such, sanitary and phytosanitary measures that conform to the Aquatic Animal Health Code are deemed to be necessary to protect human, animal or plant life or health, and presumed to be consistent with the relevant provisions of this Agreement and of GATT 1994.

responsibilities over fish health. The measures reported by participating countries follow closely the subject-matters synthesized above. They include: a) measures to prevent the introduction of exotic pathogens to the country (or part thereof); b) animal health surveillance programs; c) biosecurity measures at farm level; and d) management of disease outbreaks.

a) Preventing the introduction of disease pathogens

A first tool to prevent the introduction and spread of disease in marine finfish farms is to ensure that *fish imported into the country, transported inter-regionally, and released into the waters are free of disease*. Introduction, transport, and release of aquatic animals is strictly regulated. Accurate and comprehensive record keeping of all movements of fish for traceability purposes is an important component of the regulatory requirements (e.g. EU Directive, art. 8).

Under the U.S. Injurious Wildlife Regulations of the Lacey Act, all live salmonids and their eggs and dead whole, uneviscerated salmonids imports into the United States must be inspected by a USFWS-certified fish pathologist, fish health inspector, or veterinarian, who then certifies the shipment as disease free. Health certificates are also required for the transport of live animals. These are issued by private practice veterinarians accredited by the Animal and Plant Health Inspection Services (APHIS) under the Animal Health Protection Act. In Maine, the salmonids health inspection regulations prohibit clinically diseased salmonids from being introduced into Maine's coastal waters.

In Canada, the introduction of pathogens or pests is evaluated at the operational stage, primarily by the federal-provincial Introductions and Transfers Committees (ITC), under s. 56b of the *Fishery (General) Regulations*, is assessed by the Canadian Food Inspection Agency.

Portugal reports rules for transporting aquaculture products. All movements of aquaculture animals and products must be notified to the DGAV under D25486/2009. Faroe Islands also reports the tracking of movement of fish but also equipment. Norway also reports restrictions on moving fish both between fish health control areas and between farms. All movements of fish need to be described in an operating plan and approved by the authorities.

China requires quarantine of seeds in origin area, which allows to ban the interregional transfer of aquatic seedlings carrying viruses.

b) Fish Health Surveillance

The surveillance of aquatic animal health, including farmed animals, is an important element of the Aquatic Animal Health Code and the Council Directive 2006/88/EC (art. 10). Surveillance activities may be performed to achieve any of the following objectives: demonstrating the absence of diseases; identifying events requiring notification; determining the occurrence or distribution of endemic disease, including changes to their incidence or prevalence (or its contributing factors), in order to provide information for domestic disease control programmes or to provide relevant disease occurrence information to be used by trading partners for qualitative and quantitative risk assessment (OIE Aquatic Code, art. 1.4.1). National surveillance programs rely on the mandatory notification of suspected or confirmed presence of listed disease (see below) and inspections, sampling and diagnostic undertaken by or on behalf of competent authorities.

In Canada, the Canadian Food Inspection Agency administers the National Surveillance of Aquatic Animal Diseases, which includes surveillance of reportable diseases at different levels (country, zone, or individual facility) consistent with the international standards set by the World Organization for Animal Health (OIE). Surveillance program includes wild and farmed fish. While Norway does currently not monitor the spread of virus and bacteria from farms to wild fish, mapping of virus in wild fish is done in some rivers.

In Ireland, the Marine Institute implements a fish health monitoring programme which tests for diseases listed under Directive 2006/88/EC and other aquatic diseases of national importance. China implements the National Monitoring Network for Aquatic Disease.

Farm-specific routine monitoring for listed pathogens were additionally reported for example by US-Maine, Faroe Islands, Denmark. In Canada, licence conditions outline surveillance requirements at the farm level.

c) Farm-based measures to prevent, control and manage disease outbreaks

Participating countries report several measures adopted at the farm-level that seek to minimizing spread of pathogens between farms and to the wild.

Proper siting is considered a management tool to prevent spread of disease. Fish health authorities participate in the siting decision process to provide sectoral opinion and/or to issue a specific permit. Under the Council Directive 2006/88/EC, members of the European Union, UK and Norway are required to ensure that each aquaculture production business is duly authorized by the competent authority. Authorization shall not be granted if the activity in question were to lead to an unacceptable risk of spreading diseases to farms or to wild stocks of aquatic animals in the vicinity of the farm (Directive 2006/88/EC, art. 5.2).

A specific factor considered in the siting process is the need to maintain minimum distances between finfish farms and between farms and salmon rivers, as distance acts as a natural barrier against the spread of diseases. Canada, for example, reports that the siting process considers the connectivity between existing aquaculture sites and a proposed site, as it relates to the likelihood of spread of pathogens between farm sites. Additionally, this assessment informs regional pest and pathogen management plans, such as whether coordinated management for certain pests and pathogens would be effective.

Regulations also address husbandry practices to prevent outbreaks and spread of virus and bacteria. Good hygiene practice is specifically required under EU Directive (art. 9). Husbandry practices can be included in licenses/permits, in farm management or operational plans, in codes of good practices and/or in regulations. For example, in Canada, the conditions of licence (either provincial, territorial or federal) outline measures for the management of the abundance of pathogens. Fish health management practices at the farm level, including farm veterinarian and fish health experts, are a principal mitigation measure. In Norway, each farm needs to submit an operational plan outlining its management practices. The plan requires approval by the competent authorities, including the Food Safety Authority. Faroe Islands reports detailed regulation on management of fish farmed sites, including aspects such as disposal of dead fish and movement of equipment between areas.

Fallowing is required to break re-infection cycles (e.g. Faroe Islands, Ireland, Norway). For example, Ireland requires fallowing according to the Protocol for Fallowing at Offshore Finfish Farms. Mandatory fallowing is also reported by Norway and is implemented on an area basis.

An important approach to prevent and limit the spread of disease is the adoption of area-based measures (e.g. Norway, Faroe Islands). For example, Norway reports that coordinated and collaborative action among farms within certain areas is required. Norway considers all-in all-out zones with coordinated 2-month fallowing. The authority is also entitled to adopt zone-specific measures.

Faroe Islands has divided the ocean into 22 farming fjords. Up until 2019, only one licence holder was permitted to farm in each fjord (all of which were salmon licences) as a biosecurity measure.

Each fjord was required to maintain single year class, and to respect a mandatory fallowing period of at least 2 months between production cycles. In 2019, a regulation was introduced to allow for diversification of Faroese aquaculture. The regulation allows to expand the range of species that can be farmed in each fjord or farm area. In January 2020 five areas were opened for tenders on macroalgae cultivation, and the applications received are currently under review. Other areas are expected to be open for culturing various species in future.

d) Measures to address disease outbreaks

The notification of suspected or confirmed presence of a disease is mandatory for all listed diseases (under OIE standards and EU Directive) and other diseases of national importance (e.g. Ireland). Mitigation measures to contain and/or eradicate the pathogen are decided on a case-by-case basis (e.g. Ireland) and can depend on whether the disease is exotic, non-exotic in an area or compartment declared free of that disease, non-exotic in an area or compartment not declared free of that disease, or an emerging disease[2] (e.g. Directive 2006/88/EC, sections 3 to 6). Measures include: the designation of containment areas (e.g. quarantine area and observation (surveillance) zone under the OIE Aquatic Code, art. 4.5.5; protection zone and surveillance zone under Directive 2006/88/EC art.32), restrictions on movement of fish and equipment (e.g. Directive 2006/88/EC, art. 32), removal and safe disposal of dead fish, sanitary slaughtering, removal of fish with no clinical signs of disease, disinfection procedures, and fallowing procedures (OIE Aquatic Code art. 4.5.5.; Directive 2006/88/EC sections 3-6).

3.2.3.4 Knowledge gaps

The categories of information required to allow of a comprehensive analysis of the risk to wild fish species from viral or bacterial infections are information specific to the pathogen-host, the pathogen-environment, and the host-environment, and the combination of all three.

Additionally, information about the extent of the infection on farms, the rate or extent of spread between nets within a farm is critical to understanding and estimating the infection pressure, which can then be used to evaluate the likelihood of infection occurring and subsequently the consequence of that infection. This is illustrated in Figure 3.2.1.

[2] Emerging disease is defined in the Directive as “a newly identified serious disease, the cause of which may or may not yet be established, that has the potential to be spread within and between populations, such as by way of trade in aquatic animals and/or aquatic animal products. It also means a listed disease identified in a new host species not yet included in Part II of Annex IV as a susceptible species”.

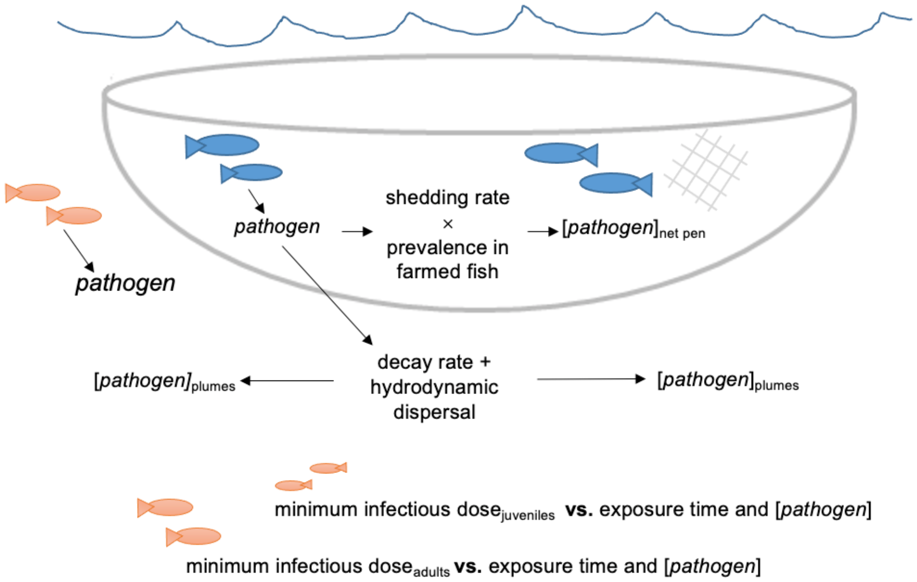

Figure 3.2.1. Wild-Farmed Infection Pathway and Data Required to Estimate Infection Pressure from Infected Farmed Fish (Source: C. Mimeault, Fisheries and Oceans Canada).

There are varying amounts of data for different pathogens, with some being the subject of many studies over decades (i.e., *Aeromonas* causing furunculosis) to emerging pathogens (e.g., piscine reovirus (PRV) strains, *Piscirickettsia*, etc.). Additionally, there are more studies using farmed Atlantic salmon and Rainbow trout than there are with wild fish species, and there are uncertainties about the application of results obtained in controlled laboratory studies to what occurs in the marine environment.

The following summarizes the key types of information that is relevant to assessing pathogen transfer in the marine environment.

Pathogen-Host Information

- Wild species susceptibility to the pathogen (salmonids and non-salmonids), including different strains or variants of the pathogen.
- Susceptibility at different host life stages (e.g yolk-sac, fry, parr, smolt, post-smolt, adult, maturing, spawners).
- What are the shedding rates for different pathogens in different hosts and at different host life stages?
- What is the shedding period?
- Do infections or shedding reappear?
- Which pathogens result in carrier states, and what factors influence whether the infected, carrier fish will develop the disease?
- For pathogens that results in carrier states, how much is shed by the asymptomatic carrier fish and is it sufficient to infect other fish within the net-pen or wild fish outside the net-pen?
- Minimum infectious dose for host species at different life stages?
- How long do susceptible wild fish need to be exposed to a given concentration of the pathogen to become infected?
- What is the outcome of this infection?
- What is the role of wild salmonids in pathogen dispersion?

- How does infection affect the behaviours of wild fish and does this make them more susceptible to other pathogens/predators?

Pathogen-Environment Information

- What is the decay rate in the environment for the pathogen?
- How long can a pathogen survive in the environment?
- What environmental (e.g., UV, salinity, temperature, etc.) or biological factors influence the length of pathogen survival and ability to infect new hosts?
- Regionally specific dispersal depends on the physical and hydrodynamic features of the area. Hydrodynamic models coupled with pathogen dispersal models can provide estimates of this dispersal and dilution, but need to be developed, refined and validated by region (i.e., area, bay, etc.)
- Will the pathogens shed from infected aquaculture fish reach the level of minimum infective dose?

Host-Environment Information

- What is the behavior of wild salmonids in areas associated with farms?
- What is the effect of low densities of wild fish, and predation pressure on the outcome of exposure to the pathogen?

Farm Infection Information

- How is the contagion dynamics in aquaculture fish?
- What percentage of the fish on a site would need to be infected to reach the minimum infective dose (e.g., concentration and duration of exposure)?
- How often will pathogens from aquaculture develop higher virulence than the similar pathogens in the nature? Does the converse occur?

Pathogen-Host-Environment

- Will transferring of pathogens from aquaculture fish to wild fish really happen? Or: Can pathogen transfer from aquaculture fish to wild fish be measured and determined as the only source of the pathogen? Is the infectious pressure from aquaculture fish sufficient to infect wild fish given the duration and proximity to the net-pen of the wild fish?
- If so: What are the consequences of infection for different relevant host species and life stages (e.g. salmon-vs-trout, life stages), e.g.
    - will the pathogen cause disease?
    - If so: will the disease cause mortality?
    - If so: will it be possible to find infected wild fish, or will infected fish die so quickly that it is difficult to find them?
    - What about non-mortality effects, like behavioural changes or reduced growth and thereby effect on the return of spawning salmon?
- For pathogens that infect a number of different marine species, does infection in these other species result in mutation of the pathogen to more virulent subspecies/strains (e.g. swine and bird flu)?

Overall, it is easy to monitor pathogens in escaped aquaculture fish, but it is very difficult to make conclusion from this fact, to the effect on wild fish populations. However, while there ae differences in the scientific characterization of different pathogens and strains, there are still many questions that remain to be answered.

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3.3 Genetic and ecological issues

3.3.1 Background

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 ecosystems, either through competition with local wild species, through disease and/or parasite transmission or through interbreeding with wild conspecifics and thus compromising their genetic integrity. In Europe, most focus on negative effects from escapees comes from intensive farming of salmonids, mainly Atlantic salmon (*Salmo salar* L.). However, potential negative effects on local species and ecosystems, should also be considered for a wider range of species.

3.3.1.1 Escapes from aquaculture facilities

Farmed fish 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. In this chapter we will focus on aquaculture in the marine area as the main volume of farmed fish in Europe is currently produced in various open cages and pens in the sea. The most common of these are floating net-pens as seen in the marine production of Atlantic salmon and rainbow trout (*Oncorhynchus mykiss*). However, escape events are also reported from land-based facilities used for rearing of the juvenile stage of Atlantic salmon (Føre and Thorvaldsen, 2020). Although open cages and pens are the standard, there are exclusively land-based production systems, as seen in the European turbot (*Scopthalmus maximus*) production, and the topic is emerging for production of salmonids in order to reduce the environmental impact. Land-based facilities also opens for production of species outside their natural environmental range.

A major risk of keeping large numbers of fish in floating net-cages is inadvertent releases of large numbers of farmed fish into the environment. This risk may be mitigated by regulating the number of fish in a given production unit. For example, in Norway the maximum number of salmon in a single cage is set to 200 000 fish. However, this number still equals ~40% of the annual return of the total Norwegian wild salmon stock (Anon, 2020). In, addition, one single salmon farm normally consists of 4-8 cages. Consequently, in a worst-case scenario, one single escape incident has the potential to outnumber local salmon-populations that may count their spawning populations in hundreds of fish, or even less.
Reasons for escape may vary. In Norway most escape incidents are caused by failure of technical equipment, often in combination with handling operations, although underlying causes may be linked to human and organizational factors (Jensen *et al.,* 2010; Føre and Thorvaldsen, 2020). Rifts in the net is the main risk-factor for escape, and there should be regulations and standards in place to ensure that the components are dimensioned according to environmental stressors like wind and waves, as well as handling of the nets in various operations like delousing, moving of fish or cleaning practices. Floating debris, like logs, and accidents with marine traffic also poses a potentially risk for escapes.

Besides escapees, another potential source of spreading of farmed fish is through spawning in cages. Pelagic/free-spawning species like European sea bass (*Dicentrarchus labrax*), gilthead sea bream (*Sparus aurata*) and Atlantic cod (*Gadus morhua*) may mature in cages, and may release eggs and sperm directly into the environment (van der Meeren *et al.,* 2012).

3.3.1.2 Effects of domestication and origin of broodstock

In general, we expect a given species to be adapted for a life in its natural environment through natural selection. Consequently, through domestication, species are prone to change its genotype as well as the phenotype through adaptations to a life in captivity (Diamond, 2002), and furthermore through active, selective breeding-programs (Gjedrem, 2000). Consequently, farmed individuals may deviate from its wild conspecifics in a wide range of traits.

For many species, populations and subpopulations may inhabit a large number of distinct geographical areas, and there may be strong local adaptations related to life-history strategies (Taylor, 1991; García de Leániz *et al.,* 2007; Fraser *et al.,* 2011), including growth, size, age of maturation, disease-resistance and/or other locally important fitness-traits. The traits most adaptive for a life in the wild may not necessarily be optimal traits in a controlled environment, and may thus erode, or even be selected against. For example, it may be highly desirable to breed for faster growth, delayed maturation or altered aggression-levels; all traits that may have negative effects in a given, *natural* environment.

Further, through founder effects, and/or intense selective breeding programs, the "effective population size" of the broodstock may also be low resulting in reduced genetic variation as compared to wild populations (Cross and King, 1983; Cross and Challanain, 1991), where sexual selection also will keep up heterogeneity, and maintain a wider genetic variation (Arnold and Wade, 1984).

Knowledge of local populations are important when considering, or assessing the risk escaped fish may pose on wild populations (Glover *et al.,* 2012; Glover *et al.,* 2013; Heino *et al.,* 2015). The size/robustness of the local population(s), whether it is distinct locally adapted populations or part of a geographically large genetic uniform population, will be essential knowledge. Also, whether the escaped fish is from highly domesticated breeding-lines, or fish genetically closer to the wild populations, will influence the level of genetic change likely to be caused by introgression (gene flow from farmed conspecifics). The level of impact from an escape event on local stocks, may therefore be expected to depend to some extent on the origin of the breeding stock used on farm level. However, even when using fish from local populations as broodstock, potential domestication effects may pose a problem in the case of escapees interbreeding with its wild conspecifics. Restocking of wild populations with hatchery reared fish can create similar risks, and epigenetic modifications through captive breeding is an emerging research topic (Barreto *et al.,* 2019).

3.3.2 Concise description of possible effects

There are a number of finfish species farmed in the North Atlantic and Mediterranean regions. Of these species, Atlantic salmon is the most researched with regard to potential impact on aquatic ecosystems due to escapees from rearing facilities. Escape of farmed Atlantic salmon, which has been under domestication selection since the early 1970´s, is considered as a major challenge to the environmental sustainability of Atlantic salmon aquaculture in Norway (Taranger *et al.,* 2011). Therefore, the principal focus of this report will be on Atlantic salmon with other species described separately.

3.3.2.1 Atlantic salmon as an example of an intensively reared species

Each year, large numbers of domesticated salmon escape from fish farms and into the wild environment. In Norway, numbers of escapees has ranged from 10 000 to 900 000, with an average of approximately 300 000 escapees per year (2001-2019). Most escapees just disappear, never to be seen again, but some survive and enter rivers where they can interact with the local population. 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.

Wild 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). Introgression of domesticated salmon may thus reduce the differentiation of wild populations (Skaala *et al.,* 2006). 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.,* 2013a), 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. The presence of farmed salmon in a river has been demonstrated to reduce the overall production of the wild population (Fleming *et al.,* 2000) and weakened populations with reduced production of wild salmon are predicted through modelling work (Castellani *et al.,* 2018; Bradbury *et al.,* 2020b). Although documentation of changes in life-history traits due to introgression is limited, altered age and size at maturation in wild salmon indviduals with a domesticated ancestry has been demonstrated (Bolstad *et al.,* 2017).

As the vast majority of the escaped farmed Atlantic salmon holds the potential to become fertile, i.e., they are not sterile, introgression (gene flow) from farmed salmon is a major concern following the detection of domesticated escapees in rivers (Bradbury *et al.*, 2020b; Glover *et al.*, 2020). However, non-reproductive interaction between farmed salmon and their wild conspecifics may also lead to genetic changes in the wild population (Bradbury *et al.*, 2020a). Transmission of pathogens or parasites from farmed to wild fish (Johnsen and Jensen, 1994; Garseth *et al.*, 2013; Madhun *et al.*, 2015; Madhun *et al.*, 2018; Thorstad and Finstad, 2018; Nylund *et al.*, 2019) may alter the selective pressure in the wild, and/or reduce the population abundance. Ultimately, this may cause alterations in the genetic make-up of the wild population (de Eyto *et al.*, 2007; de Eyto *et al.*, 2011). Competition for resources in the wild, such as food, shelter and spawning grounds, may also alter the selection pressure on wild populations (Webb *et al.*, 1991; Fleming *et al.*, 1996; Skaala *et al.*, 2012; Robertsen *et al.*, 2019).

Non-reproductive genetic interaction is also a concern when using sterile salmon, e.g., triploid salmon in salmon production. Although the numbers of farmed triploid Atlantic salmon today are low compared to the numbers of ordinary (diploid) salmon, the number is likely to increase. Non-reproductive genetic interaction between domesticated and wild salmonids are addressed in more detailed by the ICES expert group WGAFA (Working group on Application of Genetics in Fisheries and Aquaculture) and summarized in a review article by Bradbury *et al.* (2020a).

Although domesticated salmon has been documented to compete with their wild conspecifics for spawning grounds (Webb *et al.*, 1991; Fleming, 1996), their spawning success is reduced as compared to wild salmon, with males showing a less success than females (Fleming, 1996; Fleming *et al.*, 2000). Yet successful introgression of domesticated salmon, i.e. genetic changes, due to interbreeding, has been demonstrated in 2/3 of all populations investigated in Norway (Glover *et al.*, 2013; Karlsson *et al.*, 2016; Diserud *et al.*, 2019b). So far, levels of genetic introgression has been estimated for 225 Norwegian salmon populations (Diserud *et al.*, 2019b). Levels of introgression has also been estimated in some populations in Atlantic Canada (Sylvester *et al.*, 2018; Wringe *et al.*, 2018).

Level of introgression is influenced to a large degree by the proportions of farmed escapees (Glover *et al.*, 2013; Heino *et al.*, 2015; Karlsson *et al.*, 2016), but other less well studied influencing factors are properties linked to the recipient population itself (Glover *et al.*, 2012; Glover *et al.*, 2013; Heino *et al.*, 2015), or the surrounding environment. Events and factors likely to influence the risk of farmed salmon escaping and interbreeding with wild conspecifics, and the potential long-term consequences of introgression is summarized in Figure 3.2.1 (from Glover *et al.*, 2020).

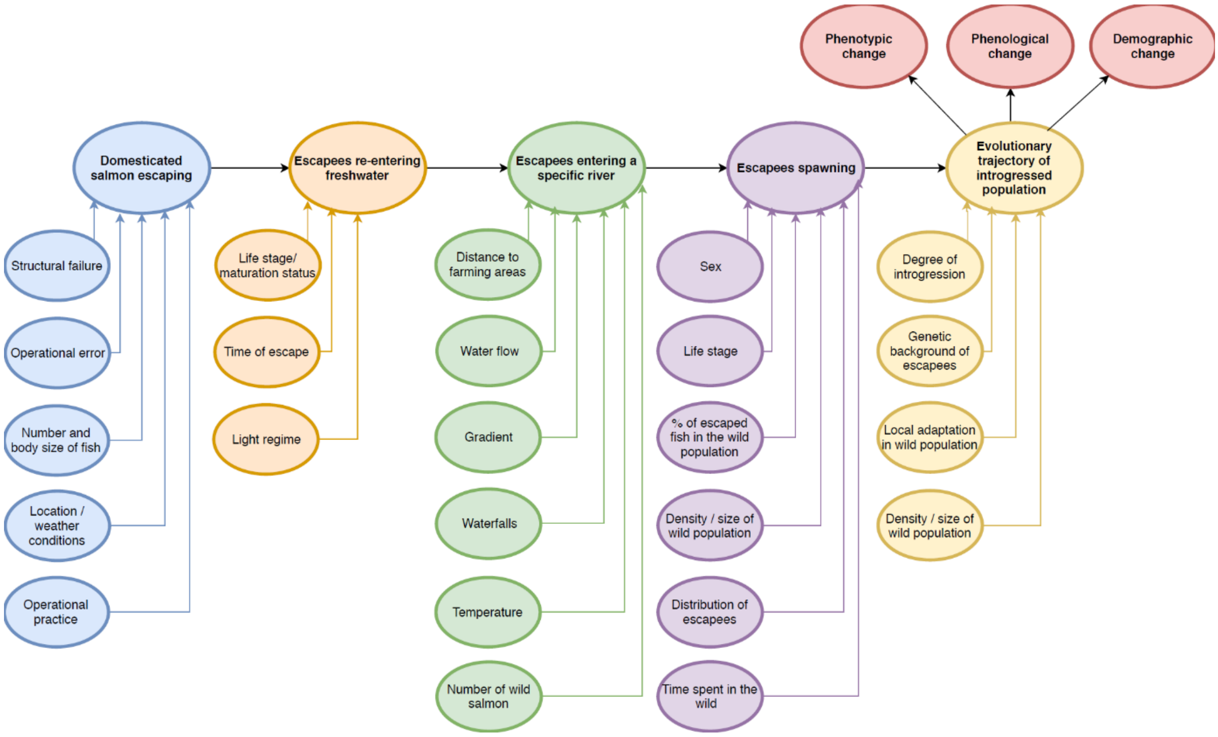

Figure 3.3.1. Events and factors likely to influence the risk of farmed salmon escaping and interbreeding with wild conspecifics, and the potential consequences of introgression (see Glover *et al.* (2020) for further details).

3.3.2.2 Other fish species in aquaculture

In some countries where the Atlantic salmon is the major species produced intensively within aquaculture, escape and impact of farmed fish on their wild conspecifics are assessed by dedicated monitoring programmes (Appendix 2).

In Norway, these assessments refer to specified requirements that fish farming activities shall not cause lasting genetic changes to wild populations. The assessments look into the likelihood of exceeding certain thresholds of environmental impacts, based on selected proxies such as the number and proportion of escaped salmon observed on the salmon rivers, and on the level of actual introgression into the wild stocks. Although Atlantic salmon are the dominant finfish species cultivated within the ICES sphere of influence, other species such as the European sea bass, gilthead sea bream, European turbot and Atlantic halibut (*Hippoglossus hippoglossus*) are also farmed extensively for food. There are also several species of fish farmed for cleaning fish purposes, but not for food. However, farmed cleaner fish used as biological control method for sea-lice may also escape and potentially interbreed with wild populations (see chapter 3.4). While salmon as a species by and large is managed population-wise, based on the fact that these populations often have a high grade of local adaptation, this is not as commonly the case in other finfish species. This is changing though, as knowledge of population structure and local adaptations emerge for a number of species, for example the wrasses (Jansson *et al.*, 2017; Jansson *et al.*, 2020; Seljestad *et al.*, 2020), where both farmed and wild-caught specimens are moved to other regions for use as cleaner-fish in salmon farms.

Recently, using the Norwegian assessments of Atlantic salmon as a paradigm, the risks that the production of European sea bass, gilthead sea bream and turbot may have on wild fish populations have been quantified (see AQUATRACE – Genetic Impacts of Marine Aquaculture

Escapees by Hofherr *et al.,* 2016). The study concluded that the current knowledge of genetic structure and dynamics of the sea bass, gilthead bream and turbot does not allow a single quantitative risk assessment covering the entire distribution area across European waters. In all three species, fish from distant populations are being used as broodstock, and various levels of selective breeding are applied among the different production facilities. Release and/or escape events of farmed fish occur, though the frequencies and magnitudes of release and/or escapes cannot be quantified precisely for any of the three species. For turbot, rough estimates of escapees and intentional releases are available. As both genetically close or very divergent fish may escape/be released for all three species, and that both general leakage from production facilities and mass escape events are both likely to occur (sea bass and sea bream), a more profound evaluation would require a case-by-case assessment of introgression and fitness risks at the level of local aquaculture regional clusters. These impact on wild populations can also be argued for in the case of farmed Atlantic halibut within Europe.

One other species farmed extensively through Europe and North America, is the rainbow trout. Recently, Atalah and Sanchez-Jerez (2020) considered three types of risks associated with the impacts of fish farm escapes, namely invasive, genetic and pathogenic. In relation to the genetic risks, the authors considered that the genetic impact of rainbow trout on wild populations, based on a number of ecological traits, was second only to the Atlantic salmon. There are no native rainbow trout populations in Europe, and so introgression is not considered a problem. There is so far little evidence that rainbow trout escapees establish viable breeding stocks in European rivers and waterways. However, in the UK, escapees from freshwater aquaculture facilities have resulted in ecological damage, most notably high predation rates on juvenile salmonid species such as the Atlantic salmon and brown trout. Furthermore, rainbow trout may be a suitable host/vector for various parasites and other pathogens that may negatively affect wild populations of native salmonids.

3.3.3 Summary of how escapees are dealt with in different countries

ICES members and China report different legislation of relevance for the regulation of escapes and their impact on wild populations. They include aquaculture legislation (e.g. Ireland[3] Norway[4]), environmental protection legislation (e.g. Denmark[5], US[6], Canada[7]), and legislation addressing species at risk (e.g. Canada[8]). Existing regulations under these legislative instruments consider measures addressing siting and farmed species selection, obligations to prevent escape events, and obligations to report and re-capture escaped fish. Monitoring programs are also in place in some reporting ICES members.

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[3] Fisheries (amendment) Act 1997.

[4] Aquaculture Act.

[5] Act for international nature protection No. 119 26.01.2017, and order for protection of nature and habitats No. 1240 24.10.2018

[6] Clean Water Act s. 402 and Effluent Limitation Guidelines are established for Concentrated Aquatic Animal Production facilities, including marine net pen aquaculture producing 100,000 pounds or more of aquatic animals per year (40 CFR Part 451).

[7] *Fisheries Act* and *Fisheries (General) Regulations*.

[8] *Species at Risk Act*.

3.3.3.1 Site and farmed species selection

The conservation of wild populations, including genetic diversity, is one of the factors considered during the assessment of a site application, including during environmental impact assessments. This assessment is sometimes supported by siting guidelines, zoning approaches, or guidance on suitable species for marine aquaculture. For example, Norway has designated National salmon fjords or rivers where salmon farming is not allowed. Through these regulations, the management aim to give special protection to a selection of the most valuable and unique wild stocks, as well as special areas (fjords) that are considered essential to the Norwegian salmon populations, as a whole. Also, a minimum distance between salmon farms and these designated salmon fjords and rivers need to be respected.

In Maine, the Department of Environmental Protection (DEP) requires that all reproductively viable Atlantic salmon placed in net pens must be of North American origin and transgenic salmonids are not authorized. Genetic evaluation information must be submitted to the National Marine Fisheries Service and U.S. Fish and Wildlife Service.

In Canada, the impact on wild populations from the unintentional release of cultured organisms is considered at the pre-operational stage and is linked to fiduciary responsibilities associated with the *Species at Risk Act*. While siting decisions are mostly made on a farm-to-farm basis, there is specific consideration of minimum distances between farm proposed sites and salmon-bearing streams. It is also considered by the Introductions and Transfers Committee in the assessment of requests for non-routine introductions or transfers, under the *Fishery (General) Regulations*.

3.3.3.2 Measures to prevent escape episodes

Farm operators are generally required to take measures to prevent escapes (e.g. Ireland, Faroe Islands, Norway). More specific obligations are included in regulatory regimes. First, there are specific obligations regarding the construction, maintenance, and inspection of containment structures, which can include compliance with standards. For example, Ireland requires compliance with the "Structural Design Protocol for Marine Finfish Farms April 2016". Monitoring is carried out by DAFM Engineering Division. Norway also requires compliance with the Norwegian national standard NS 9415:2009 "Marine fish farms: Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation". In Faroe Island, equipment is designed according to the physical stress at the locations, and inspection of net cages occur regularly. Denmark also undertakes regular control of nets. The development of a national containment standard for marine finfish cages is under elaboration in Canada.

Second, farmers may have an obligation to submit and maintain a containment management plan detailing measures to prevent escapes as well as procedures to be adopted in case of an escape. For example, as part of the licensing process, Maine requires a Containment Management System (CMS) Plan that includes escape response, record keeping, and monitoring procedures to verify the effectiveness of escape control mechanisms. Washington also requires an escape prevention plan that includes how to minimize risk of escapement and tracking how many fish are lost. The Washington Department of Fish and Wildlife has authority to inspect facilities, at least on an annual basis, to determine conformity with respect to preventing and recapturing escapes.

3.3.3.3 Measures to be adopted in case of an escape

If any escape occurs, regulations consider an obligation to report the escape (e.g. Faroe Islands, Norway, Canada), or to report an escape that exceeds a certain threshold (e.g. Maine, Washington), to the responsible authorities shortly after it is detected. Regulations also consider an obligation to recapture escaped farmed fish (e.g. Norway, Maine, Washington, Faroe Islands). The submission of a management plan (e.g. Ireland) or an audit of the containment system plan (e.g. Maine) can follow a reported incident.

In Ireland, for example, operators must contact Department of Agriculture, Food and the Marine, the Marine Institute, and Inland Fisheries Ireland within 24 hours of an escape. A suitable management plan (which may include recapture) will then be agreed among the relevant parties.

Maine requires an e-mail notification within 24 hours of a known escape of 24% or more of a cage population, as well as implementation of the containment management system (CMS, see above). Within 30 days of an escape, the CMS must be audited. Any time a CMS audit identifies deficiencies, a written report must contain a corrective action plan.

Washington also establishes obligations regarding reportable fish escapes, which is a known escape of 24% or more of a cage population. The escape must be reported within 24 hours of detected. The permittee must implement the escape prevention plan accompanying the marine finfish aquaculture permit application (see above) and which includes procedures to attempt to recapture escaped fish.

In Canada, reporting of escaped fish is managed through the conditions of licence that are set by the provincial governments or by Fisheries and Oceans under the *Pacific Aquaculture Regulations* in British Columbia. Recapturing escaped fish requires a finding licence issued by Fisheries and Oceans Canada.

Norwegian farmers are obliged to report immediately, and attempt recapture following a fish escape within a 500 meter zone, as a part of an already approved plan. The Norwegian Directorate of fisheries may through regulations increase this recapture zone in the marine environment, or even impose on the farmer to plan and implement monitoring and recapture-programmes in relevant rivers. Additionally, the Norwegian Directorate of Fisheries has stand-by procedures for removal of escapees from rivers if not covered by the OURO program (see monitoring below) as and when needed.

Despite the reporting obligations, in some cases domesticated fish with no known sources, appears in spawning areas of wild fish. Some ICES members have put in place tagging programs to determine the origin of the escapees. For example, farmers in Maine need a tagging-plan, approved by the National Marine Fisheries Service and U.S. Fish and Wildlife Service, to determine the origin of the fish. Norway has developed and implemented a DNA method to trace unreported escapees back to their farms (and owners) of origin (Glover, 2010). The program is administered by the Norwegian Directorate of Fisheries. Tracking methods combining DNA and trace-element analysis are also developed, and may be implemented in Norwegian salmon farming, thus aiming to track individual fish down to site of escape.

3.3.3.4 Monitoring practices

ICES members report knowledge gaps in the status of wild salmon (e.g. Faroe Islands) and of the impacts of fish farm escapees on wild stocks (e.g. Ireland). Despite this knowledge gap, only a limited number of ICES members report monitoring programs. Faroe Islands commenced surveys on wild trout in 2019 as a project funded by the fish farmers association. Canada, in turn, reports that monitoring and mitigation of domesticated escapees are initiated when necessary (ad hoc), and that counting fences to intercept escapees are installed in some rivers.

The most comprehensive monitoring program was reported by Norway. The vision of the Norwegian government with respect to escapees and genetic interactions with wild conspecifics is that escapes of farmed fish shall not change the local adaptation, and the genetic characteristics of wild salmon populations. This vision is supported by a program that comprises four major elements: a) The Norwegian national monitoring program of escapees in rivers; b) monitoring genetic status of wild salmon populations with molecular markers; c) risk assessment of Norwegian aquaculture to determine areas in which there is a risk of further introgression of escapees; and d) the official statistics for the numbers of farmed fish reported to escape (available at https://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Roemmingsstatistikk). The three first elements are described below.

a) *National Monitoring Program*. The occurrence of escaped farmed salmon in local, wild populations has been monitored in Norwegian rivers since 1989. The current **National Monitoring Program** was initiated in 2014 and includes surveys of approximately 200 rivers representing half of the rivers known to support anadromous populations, covering ~90% of the wild salmon production. The monitoring program is based upon the catches of farmed salmon observed from angling, spawning-ground surveys, fish-traps and prespawning surveys through snorkeling. This is a permanent program resulting in an annual online report (Anon, 2019) with a supplementary file where all surveyed rivers are described in greater detail. The proportion of farmed escapees in Norwegian rivers are categorized into the following categories: low (0-4%), moderate (4-10%) and high (>10%), as suggested by (Taranger *et al.*, 2011). A summary of the program's activity prior to (Diserud *et al.*, 2019a) and after 2014 (Glover *et al.*, 2019) was recently published.

   In rivers where the National monitoring program for escapees has provided data that the proportion of farmed escapees is above the thresholds (>10%), a government implemented and fish-farmer financed fund (OURO http://utfisking.no/) canalizes resources to remove farmed escapees from the spawning grounds (mitigation). In the process of selecting rivers for the program, OURO also uses knowledge from other sources, such as the Norwegian Standard for Wild Salmon https://lovdata.no/dokument/SF/forskrift/2013-09-20-1109.

b) *Monitoring genetic status of wild salmon populations with molecular markers*. Introgression of farmed escapees in wild populations has been quantified by molecular markers in 225 rivers/populations (Diserud *et al.*, 2019a), and represents one of the main elements in the Norwegian Standard for Wild Salmon which is used, together with data from the monitoring program, to inform the OURO process for mitigation. Another element in the standard used to describe the robustness of the wild populations is level of achievement (or surpass) of adult spawning target (Hindar *et al.*, 2007), defined as the number of eggs required to utilize a rivers full potential for juvenile production.

c) *Risk assessment of Norwegian aquaculture to determine areas in which there is a risk of further introgression of escapees*. Since 2011, Norway has conducted an annual risk assessment of the environmental problems arising from salmonid aquaculture, including the risk of negative impact from escaped fish on wild salmon populations. Until recently, the foundation of the annual risk assessment of farmed escapees was to indicate where there are more escapees observed in rivers than acceptable. The proportion of farmed escapees in Norwegian rivers was reported, based on the thresholds and classification of the National Monitoring Program (see above). A proportion of farmed escapees higher than 10% would indicate large risk of genetic changes in the wild populations (Taranger *et al.*, 2011). Observed frequency of escaped farmed salmon in a river is a significant, but not the only factor explaining the variation in introgression levels documented among rivers in Norway (Heino *et al.*, 2015; Karlsson *et al.*, 2016). Therefore, the risk assessment was updated in 2019, and there are now five factors included in the risk assessment for further introgression of domesticated escapees (Grefsrud *et al.*, 2019; Glover *et al.*, 2020). Together these five factors represent the numbers and proportions of domesticated escapees in spawning populations and the resilience of the wild population. These factors are: (1) the number of escaped fish reported to the authorities

(NDF); (2) the observed proportions of escapees in a river as reported by the monitoring program; (3) the removal of farmed escapees prespawning as documented by OURO; (4) the demographic status (spawning target status) and (5) the genetic status (level of introgression) of the wild populations.

The coastline of Norway is divided into 13 aquaculture productions zones, and the production in each zone is regulated biannual according to impacts of salmon lice from aquaculture on wild salmonids. The risk assessment for further introgression of domesticated escapees in wild salmon populations is also summarized according to these zones (Figure 3.3.2). Each zone is categorized as having low (green), moderate (yellow) or high (red) risk of further introgression of domesticated escapees based on the five factors indicated above. The 2019 assessment revealed that rivers in 10 out of 13 productions zones display moderate to high risks of further introgression.

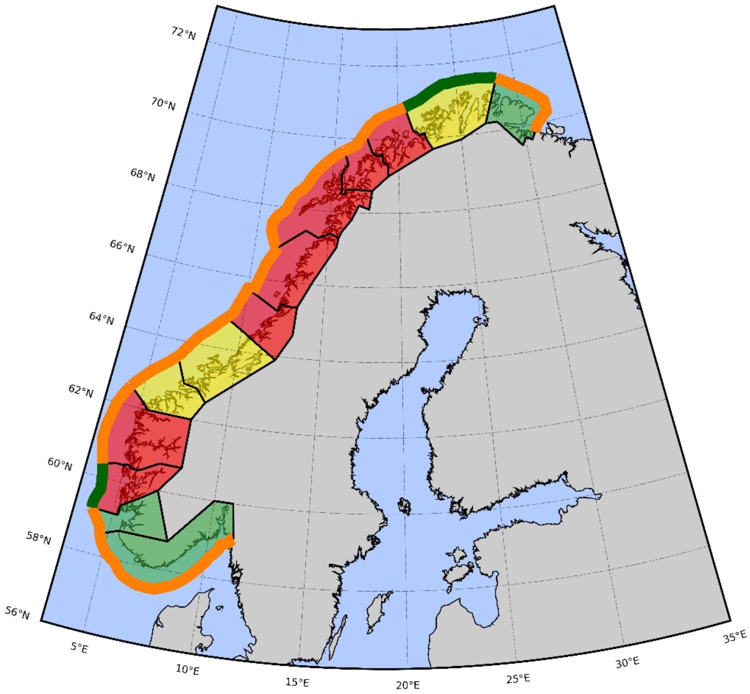

Figure 3.3.2. Map showing the 13 aquaculture production zones covering Norway, and a summary of the results of the risk assessment for further introgression of domesticated escapees in wild salmon populations. Green-yellow-red colouring of the coastline illustrates low, moderate and high risk for further introgression of domesticated salmon in rivers within each zone. Green-orange-red lines on the outside the coloured coastline represent high, moderate and low status of knowledge for these estimates (see Glover *et al.* (2020) for further details).

3.3.4 Knowledge gaps and emerging issues

Knowledge regarding escapees and the genetic impact of Atlantic salmon on wild populations is significantly greater than that of the other fish species produced by intensive aquaculture. This has been the result of legislation, regulation and a proactive approach to salmon farming by the major producers. Therefore, the knowledge gaps differ to a large degree between salmon and other farmed species, and are dealt with separately.

3.3.4.1 Atlantic salmon

- The magnitude of escape and the likely causes of escape is not always clear. More detailed and/or uniform reporting practices is needed to understand the scope of escape through leakage, and the likely causes of acute escape events.

- Dedicated monitoring programmes for documenting the appearance of escaped farmed salmon in rivers is not established in most salmon farming countries. Nor are action plans for removal of farmed escapees from rivers to reduce both ecological and genetic impact on the wild populations.

- Level of introgression is well demonstrated in Norway, and for some populations in Canada. However, this knowledge is still lacking for most countries farming Atlantic salmon.
- The proportions of farmed escapes observed in a river cannot solely explain the level of introgression, and more research is needed in order to understand how environmental factors are affecting introgression levels.
- The resilience of the wild populations toward introgression will be influenced by population specific properties and robustness, and this knowledge is limited in some areas.
- Documentation of phenotypic alterations in wild populations due to introgression is scarce, and more research is required to understand the long-term biological consequences of introgression.
- The development and implementation of sterile salmon in order to eliminate the genetic impact of farmed escapees is ongoing, but not without challenges. Multiple methods are now developed, or under development, such as pressure induced triploid salmon (implemented, often through green licences) and germ cell free crispant salmon (under development). While this reduces the direct genetic impact, the ecological impact of such escapees should be investigated further.
- The development of closed-containment aquaculture both on land and at sea is ongoing. This in order to eliminate and/or reduce the genetic impact of farmed escapees, and well as to reduce the negative ecological impact on wild populations through parasite and disease transmission.

3.3.4.2 Other aquaculture fish species

- Customized legislation regulating technical requirements and escape events of species with deviating biology is limited.
- More research is needed in order to assesses the genetic structure, life history and robustness of wild populations in all aquaculture species.
- Thresholds towards risk of ecological and genetic impact of escapees are not established at the species level.
- Monitoring programmes are not established for most aquaculture species. However, transferable knowledge from countries/species such as Norway/Atlantic salmon, is available.

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3.4 Cleaner fish

3.4.1 Introduction

Ectoparasitic caligid sea-lice are a key environmental interaction for farmed salmonids (Section 3.2.1.1 Parasite and pathogen transfer from marine finfish aquaculture to wild fish), as well as impacting on farmed fish health and welfare, productivity and economics (Brooker *et al.*, 2018). An integrated approach to control sea-lice has developed which combines area management and synchronized fallowing, chemotherapeutants, mechanical lice-removal (brushing, pressure washing), exposure to elevated temperature or reduced salinity, modifications to the net-pen environment, and cleaner fish (Murray, 2016; Brooker *et al.*, 2018; Gentry *et al.*, 2020).

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 poly-culture 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* in the eastern Atlantic (Skiftesvik *et al.*, 2014; Riley *et al.*, 2017; Gonzalez and de Boer, 2017); cunner (*Tautogolabrus adspersus*) in Canada (Costa *et al.*, 2015). 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.*, 2018; Powell *et al.*, 2018a).

Wild-caught cleaner fish were first used in salmon farming in the late 1980s / early 1990s in Norway, UK and Ireland (Deady *et al.*, 1995; Treasurer, 1994; Skiftesvik *et al.*, 2014; Riley *et al.*, 2017; Brooker *et al.*, 2018). The practice then decreased when new chemotherapeutants were introduced but, as resistance emerged, cleaner fish returned to the armoury of sea-lice treatments and are currently used across Norway, Ireland, UK, Faroes, Iceland and Canada (Gonzalez and de Boer, 2017; Brooker *et al.*, 2018). Recent analyses suggest that the impact of cleaner fish on sea-lice is variable, and their efficacy may be lower than previously thought (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 (Powell *et al.*, 2018a). Treatment requires a ratio of between 1:7 and 1:150 cleaner fish: salmon (Riley *et al.*, 2017; Gonzalez and de Boer, 2017; VKM *et al.*, 2017; Brooker *et al.*, 2018). Cleaner fish are frequently replenished due to high mortality after deployment (VKM *et al.*, 2017). Brooker *et al.* (2018) indicated that in 2016, the salmon industry deployed 37.4 million cleaner fish in Norway, and 3.0 million in the UK. Use has since increased, with 60.6 million cleaner fish deployed in Norway in 2019 (Norwegian Directorate of Fisheries, 2020).

Initially all cleaner fish were wild-caught but with a recognized long-term demand, aquaculture production started around 2011 (Brooker *et al.*, 2018). Lumpfish have proven easier to culture than wrasse, and mainly farmed juveniles are deployed, although this production is still largely reliant on wild-caught broodstock (Whittaker *et al.*, 2018; Brooker *et al.*, 2018; Powell *et al.*, 2018a; Guðmundsdóttir *et al.*, 2019; Norwegian Directorate of Fisheries, 2020). Breeding programmes to close the lumpfish life cycle using farmed broodstock have recently started in Norway and other regions. In contrast, the majority of wrasse deployed are wild-caught, with a minority supplied from farmed stock (VKM *et al.*, 2017; Norwegian Directorate of Fisheries, 2020). Wrasse aquaculture has focused on ballan wrasse, although other wrasse species are being cultured in Scotland (Skiftesvik *et al.*, 2013; Gonzalez and de Boer, 2017; Munro, 2019).

The potential environmental interactions associated with the use of cleaner fish (Grefsrud *et al.*, 2018, 2019) are: 1) Fisheries for wild stock; 2) Escape of non-indigenous genotypes; and 3) Pathogens. It should be noted that because cleaner fish use is a relatively new and evolving development in aquaculture, regulation is also developing. Where authorities are aware of the potential for negative environmental interactions but there is an absence of information and/or risks appear low, the need for sea-lice control may outweigh adoption of a precautionary regulatory approach.

A (non-environmental) issue for cleaner fish that has been highlighted is animal welfare (Brooker *et al.*, 2018). In the UK, mortality of wild-caught wrasse associated with capture, holding and transport is reported to have reduced markedly as good practice has developed with experience (see also Skiftesvik *et al.*, 2014). Loss rates after deployment in net-pens are recognized as high (Brooker *et al.*, 2018); causes are undocumented but thought to include malnutrition, disease, injury, predation by salmon and escape (VKM *et al.*, 2017). Such losses further increase the demand for, and deployment of, wild-caught and farmed cleaner fish exacerbating the potential environmental interactions. As with any species new to aquaculture, suitable environmental conditions, diets, husbandry and pathogen control methods are being determined, and domesticated strains selected for suitability to culture are not yet available. There is the additional difficulty of poly-culture in meeting the potentially divergent environmental needs of cleaner fish housed with salmonids. Additional welfare concerns are morphological deformities in farmed fish, stress, and humane killing of survivors when mixed with harvested salmon.

3.4.2 Cleaner fish - fisheries for wild stock

For security of supply, commercial aquaculture aims to have full control of production at all stages of the life cycle (Powell *et al.*, 2018a). However, for any species new to aquaculture, wild-caught broodstock are required to provide the initial progeny (with subsequent broodstock being selected from farmed cohorts based on performance under culture conditions). Fisheries for wild-caught juvenile fish may also develop for species where: hatchery supply does not meet demand; hatchery production is not commercially viable (i.e. if wild inputs are cheaper); "closing the life cycle" proves problematic. The environmental interactions of such fisheries for live wild stock are controlled through existing or new fishery management measures. (c.f. Section 4.5 Interaction with wild species, for shellfish).

Fisheries for wild cleaner fish are recognized as an alternative source of income for inshore fishers as well as supporting aquaculture (Riley *et al.*, 2017; Gonzalez and de Boer, 2017; VKM *et al.*, 2017). Fisheries for mature lumpfish for roe (caviar) pre-date (and greatly exceed) fisheries for cleaner fish broodstock; regulation is therefore in place for lumpfish fisheries in some countries (Powell *et al.*, 2018b). In contrast, wrasse had no prior history of commercial exploitation and initially fell outside existing fisheries regulations as "non-quota" species, so are the focus here.

With respect to wild finfish inputs to aquaculture, it is also worth noting that:

- In Norway there has been interest in "capture-based aquaculture" of cod *Gadus morhua*, i.e. holding large wild-caught fish for 6-8 months until harvest at a time of year when the fishery supply is limited and prices increase (Dreyer *et al.*, 2008). The wild stocks are subject to pre-existing fishery regulations, and specific regulations were introduced to address the practice (Dreyer *et al.*, 2008).
- Spain reports increasing inputs of wild Atlantic bluefin tuna *Thunnus thynnus* to aquaculture, with 2,749 tonnes valued at €32.3 M in 2016 (https://ec.europa.eu/eurostat/data/database). Tuna are caught by a purse-seine fleet based in Spain and France (and Italy) and on-grown in nearby net-pens https://ec.europa.eu/fisheries/marine_species/wild_species/bluefin_tuna. Atlantic bluefin tuna are listed by the International Union for Conservation of

Nature (IUCN) as endangered, and fisheries are subject to international scrutiny and management https://ec.europa.eu/fisheries/marine_species/wild_species/bluefin_tuna_en).

- Denmark, Estonia, Germany, Spain and the UK report inputs of juvenile wild European eel *Anguilla anguilla* to aquaculture: in 2016, 9 tonnes valued at €2.6 M (https://ec.europa.eu/eurostat/data/database). The juvenile eel are on-grown in closed recirculation systems in the Netherlands and Denmark (and Italy) https://ec.europa.eu/fisheries/marine_species/farmed_fish_and_shellfish/eel. The European eel is listed by the IUCN as critically endangered, and fisheries are subject to international scrutiny and management (https://www.ices.dk/community/groups/Pages/WGEEL.aspx. An additional measure to mitigate the potential impact of juvenile eel fisheries is that 60% of catches of juvenile eel must be used to restock wild habitats (*EC Reg 1100/2007 Establishing measures for the recovery of the stock of European eel* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007R1100andfrom=EN).

3.4.2.1 Concise description of cause

New fisheries have developed for live wild wrasse, which 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 by fish transporters for road transport to salmonid farms, but may also deliver directly to farms (VKM *et al.*, 2017; 2019).

In both Norway and the UK, wrasse fisheries have extended over time from the salmon farming areas in the north to more southerly areas (Gonzalez and de Boer, 2017). In Norway, the numbers of wild wrasse landed for use as cleaner fish rose from virtually zero to 20 million fish p.a. in 10 years (Gonzalez and de Boer, 2017; Brooker *et al.*, 2018). Wild capture continued to increase to a peak of 24 million fish in 2017, but has since fallen to around 17 million in 2018-2019 (Norwegian Directorate of Fisheries, 2020). In the southwest of England, a new wrasse fishery emerged in 2015, described as a "gold-rush" due to the high value of each fish and initial lack of fishery management (Riley *et al.*, 2017; Hjul, 2017).

The introduction of fishery regulations in Norway and the UK has typically lagged behind the development and expansion of the new wrasse fisheries. The targeting of several wrasse species within a single fishery complicates regulation.

3.4.2.2 Concise description of possible effects

The potential effects of fishing pressure on wrasse populations and the inshore ecosystem include (Darwall *et al.*, 1992; Riley *et al.* 2017; Gonzalez and de Boer, 2017; Brooker *et al.*, 2018; Faust *et al.*, 2018, Halvorsen *et al.*, 2016, 2017a, 2017b; Olsen *et al.*, 2019; Kindsvater *et al.*, 2020):

- 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.

The life history of wrasse (e.g. limited home range, complex social hierarchy, protogynous hermaphroditism and a skewed size-dependent sex ratio, investment in nesting, demersal eggs, longevity) makes them theoretically vulnerable to fishing pressure (Muncaster *et al.,* 2013; Halvorsen *et al.,* 2016; Halvorsen *et al.,* 2017b, Riley *et al.,* 2017; Kindsvater *et al.,* 2020). There is evidence of reduced wrasse abundance and altered size structure in fished areas compared to nearby protected areas (Halvorsen *et al.,* 2017a). A mark-recapture study in western Norway indicated that commercial fishing removed up to 40% of corkwing wrasse over a two month period (Halvorsen *et al.,* 2017b). Elsewhere, there are anecdotal reports from recreational divers of reduced wrasse abundance in the UK (Riley *et al.*, 2017) and Canada (Newfoundland and Labrador).

Wrasse that are retained by fishing gear, but outside a regulatory size range (or fish farm requirement) will be discarded. Recent data from Norway indicate that ~30 % of goldsinny and corkwing wrasse are discarded, most of which are smaller than the legal minimum size. In contrast, only 3% of ballan wrasse is discarded, indicating that the minimum size limit (14 cm) only protects a very small proportion of the catch. Cuckoo and rock cook wrasse are rarely in demand as cleaner fish in Norway and most are discarded regardless of size (Halvorsen *et al.*, 2020a). Such discarding reflects the fishing gear and mixed species fishery. There is a lack of information on survival of discarded wrasse which will be affected by the gear type, retention time, expansion of the closed swimbladder when brought to the surface (VKM *et al.*, 2017), and subsequent handling and release.

Wrasse fishing gear may also capture “bycatch” of other species such as cod, pollack, eel, lobster green crab and brown crab (Skiftesvik *et al.,* 2014; Halvorsen *et al.,* 2017a; 2020a; 2020b). The impacts on local populations will similarly depend upon the size range caught, the proportion landed, and the survival of discards.

3.4.2.3 Summary of how it is dealt with in different countries

The impacts of fisheries on wild wrasse populations and inshore communities are currently unknown, but will be restricted to those ICES countries where wild cleaner fish are fished. The difficulty of regulating wrasse fisheries is compounded by the mix of target species, which will vary between locations.

Existing regulation

Approaches to the regulation of new wrasse fisheries appear to differ between countries. In Norway and the UK, regulations were introduced after the fisheries had started and are evolving as the fisheries develop and information becomes available. In Canada, fishers initially request access to fish wrasse populations; established processes are then followed for the issue of licences to retain new species, and fisheries regulations and management plans are developed that are responsive to the requests.

In Norway, wrasse fishery management measures were initially introduced in 2011- a minimum landing size and closed season to protect spawning stocks. These measures have since been refined and additional licencing, restrictions on fishing gear (e.g. defined trap entrance/escape opening sizes) and quotas have been introduced (Gonzalez and de Boer, 2017). A quota of 18 million was introduced in in 2016 (www.fiskeridir.no), but was not properly enforced until 2018. This quota was based on the reported catches up to 2015, and catch-per-unit-effort (CPUE) data from reference fishers along the coast. This method will continue to be used until more knowledge of population sizes and dynamics are available.

In Scotland (UK) voluntary wrasse fishery measures are in place, including seasonal closure of the fishery, restrictions on the number, design and deployment of traps and publication of catch data (Anon, 2019; Scottish Government, 2020). However, a consultation is underway (May 2020) with a more extensive range of mandatory controls being proposed, including licencing, data reporting, vessel tracking, fishery observers, a closed season, trap design and operation, and minimum and maximum landing sizes (Scottish Government, 2020).

In England (UK), Inshore Fisheries and Conservation Authorities (IFCAs) are responsible for the fisheries and have introduced a variety of management measures (Riley *et al.*, 2017). Such measures include: licensing, effort limitation, identification of gear, minimum and maximum landing sizes, closed areas / no-take zones, maximum fishing depths, closed seasons, reporting of catch data, and biosecurity and husbandry requirements (Southern IFCA, 2017).

Monitoring practices

In Norway, the total number of wrasse landed has been reported to the Norwegian Directorate of Fisheries since 1998, with a breakdown by species since 2015 (Norwegian Directorate of Fisheries, 2020). The quality of these official statistics is considered to have been poor initially, but to have improved over time (Skiftesvik *et al.*, 2014). Additional fisheries-dependent data on fish sizes and CPUE is collected from 12-16 fishers in different regions every season, but the monitoring programme has undergone considerable change so a time-series on abundance and size structure is still under development (Halvorsen *et al.*, 2020b) (https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2020-3). A recent study clearly shows that catch data must be standardized for fishing depth and other environmental variables if CPUE is to be used as an abundance index (Halvorsen *et al.*, 2020a).

In the UK, current fishery landings data for wrasse are similarly considered to be unreliable due to underreporting and uncertain species recording (Riley *et al.*, 2017). In Scotland, the salmon farming industry has recently started to publish catches, and mandatory reporting may be introduced. In southwest England, IFCAs may require submission of catch rate data as a potential means to track population size.

Fishery-independent monitoring data for wild wrasse populations is lacking; the rocky, inshore habitats are unsuitable for routine sampling/assessment methods (Riley *et al.*, 2017). Skiftesvik *et al.* (2014) monitored wrasse populations in a fished area using static gear, and suggested that such sampling should be introduced to monitor fished wrasse populations.

3.4.2.4 Emerging issues and knowledge gaps

The sustainability of wrasse fisheries is largely a knowledge gap. The delay associated with establishing catch reporting (i.e. avoiding underreporting and species misreporting; Skiftesvik *et al.*, 2014) hinders attempts to use fishery data to track any impacts of wrasse fisheries. Gear modifications to decrease discards, and reducing the mortality of discarded and retained fish before deployment have been highlighted as important areas for investigation (Skiftesvik *et al.*, 2014; Gonzalez and de Boer, 2017).

Riley *et al.* (2017) suggested that research on wild wrasse should address life history, movements, population structure and status; such information is becoming available to advise regulation of wrasse fisheries. Skiftesvik *et al.* (2014) recommended a closed season during the spawning period – both to allow contribution to recruitment and to avoid a period when the fish appear sensitive to handling and experience greater mortality rates during capture, storage and transport. Halvorsen *et al.* (2016) suggested a maximum size limit to protect nest guarding males in corkwing wrasse; this has not been implemented in Norway, but has been adopted by the UK's Southern IFCA. Skiftesvik and Halvorsen (2019) suggested a maximum size limit for ballan wrasse of 28 cm to protect males (which change sex from female at 34-40 cm; Muncaster *et al.*, 2013) and an increased minimum size limit (22 cm) to protect juveniles.

The aquaculture industry and research community are investing in captive breeding of cleaner fish and broodstock selection, and full cycle cultivation of lumpfish and ballan wrasse is expected to meet industry demand in the coming years (Brooker *et al.,* 2018). Associated research requirements include control of maturation for year-round production and to eliminate the requirement for wild broodstock (Powell *et al.,* 2018a).

In 2016, it was estimated that the proportion of deployed cleaner fish of farmed origin had risen to 68% in the UK and 46% in Norway and (Brooker *et al.,* 2018). The proportion in Norway has since risen to 71% in 2019 (99% for lumpfish, 32% for ballan wrasse, and 0% for goldsinny, corkwing and rock cook wrasse) (Norwegian Directorate of Fisheries, 2020). Due to use of different size/species of wrasse at different stages of the production cycle, demand for wild-caught fish is likely to persist (Gonzalez and de Boer, 2017). Cleaner fish surviving at the end of a production cycle are killed to eliminate the risk of disease transfer to a new stock; this practice may merit review to reduce pressure on wild stocks (Gonzalez and de Boer, 2017; VKM *et al.,* 2017; Powell *et al.,* 2018a).

3.4.3 Cleaner fish - escape of non-indigenous genotypes

3.4.3.1 Concise description of cause

Recovery of stocked cleaner fish from net-pens after deployment is low (VKM *et al.,* 2017; Brooker *et al.,* 2018). The loss is largely attributed to mortality, but escape is likely to contribute (Deady *et al.,* 1995; Skiftesvik *et al.,* 2014; VKM *et al.,* 2017). Cleaner fish may escape by passing through the mesh (small fish only) or through areas of net damage (VKM *et al.,* 2017). Survivors at the end of a production cycle may also have been intentionally released (Gonzalez and de Boer, 2017; Faust *et al.,* 2018) although this is against Norwegian regulations (VKM *et al.,* 2017). 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.

To meet the high demand, cleaner fish are being sourced with little regard for the genetic origin. 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). Such northerly translocation may be outside the natural distribution of some species. In Scotland, the farmed lumpfish deployed originate from eggs imported from Iceland and Norway (Whittaker *et al.,* 2018). Wild wrasse caught from the west coast of Scotland have been deployed in Shetland (Hall *et al.,* 2013), and wrasse from the southwest of England are transported over 1,000 km for use in Scotland (Riley *et al.,* 2017).

Geographic differences in genotype have been demonstrated for cleaner fish. The geographic scale for such differences vary between species, which is likely to reflect differences in population connectivity associated with dispersal during the life history, habitat linkage and oceanographic features (Gonzalez and de Boer, 2017; Whittaker *et al.,* 2018), and possibly the method used for genetic analysis:

- goldsinny wrasse differ between locations within Norway (Sundt and Jørstad, 1998; Skiftesvik *et al.,* 2014; Jansson *et al.,* 2017);
- ballan and corkwing wrasse, show weaker differences within such geographical regions but strong genetic differences between regions (D'Arcy *et al.,* 2013; Robalo *et al.,* 2012; Knutsen *et al.,* 2013; Seljestad *et al.,* 2020);
- lumpfish show genetically distinct populations, but only over much larger geographical areas (USA + Canada; Iceland; Faroe Islands + Ireland + Scotland + Norway + Denmark;

English Channel; Baltic Sea) with the Icelandic population also being phenotypically distinct (Pampoulie *et al.*, 2014; Jónsdóttir *et al.*, 2018; Whittaker *et al.*, 2018).

Individual wrasse from different populations have been shown to interbreed (Gonzalez and de Boer, 2017). In 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 (Faust *et al.*, 2018) and introgression as discussed for salmon (Section 3.3 Genetic and ecological issues). 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). Genetic impacts may be exacerbated if local population sizes have been reduced by cleaner fish fisheries.

3.4.3.2 Concise description of possible effects

The effects of hybridization on local wild populations of cleaner fish are unknown and hard to predict (Faust *et al.*, 2018): fitness may reduce due to genetic incompatibilities, reduced adaptation to the local environment or increased susceptibility to pathogens; alternatively fitness may increase due to introduction of favourable genes or sheltering of deleterious alleles.

3.4.3.3 Summary of how it is dealt with in different countries

The issue is common to all countries where wild cleaner fish are translocated over large distances or originate from imported ova. This issue is therefore of potential significance for both lumpfish and wrasse in Norway and the UK.

Existing regulation

Within the EU, Regulation 304/2011 "*concerning use of alien and locally absent species in aquaculture*" https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32011R0304 controls use at species level; however, it does not regulate use of fish that may differ in genotype to the local population.

In Canada, the *Fisheries (General) Regulations* s56 requires the determination of risk to the genetic integrity of local populations prior to issuing a licence for the introduction or transfer of fish into an area, including into net-pen aquaculture facilities.

Regulations concerning containment (see Section 3.3 Genetic and ecological issues) should apply equally to the main farmed stock and cleaner fish.

Monitoring practices

No regulatory monitoring of the genotype of cleaner fish is undertaken. In Norway and the UK, reporting of the source of cleaner fish is not required (Faust *et al.*, 2018). In Canada, however, the source population of the cleaner fish is considered as part of the licencing to move cleaner fish into net-pens.

Although containment regulations require farmers to inform authorities of escape events, such reporting typically only applies to the target species cultured and not cleaner fish (Faust *et al.*, 2018).

3.4.3.4 Emerging issues and knowledge gaps

There is a recognized need for further studies on the population genetics of cleaner fish across ICES countries, to assess the potential risks of translocated genotypes (Riley *et al.*, 2017; Brooker *et al.*, 2018; Faust *et al.*, 2018).

The loss of cleaner fish during deployment and the magnitude of escapement merits attention (Whittaker *et al.*, 2018). It has been suggested that the behaviour of cleaner fish (grazing; association with surfaces) may facilitate escape, so containment of cleaner fish should be considered in net-pen design.

The risk of genetic introgression when escapes do occur could be mitigated by the aquaculture industry producing sterile cleaner fish; such production would also eliminate the fishing pressures on wild cleaner fish populations (Whittaker *et al.*, 2018; Powell *et al.*, 2018a). An interim goal would be to develop locally-sourced broodstocks, although the likely genetic selection associated with domesticated lines would not eliminate the risk of introgression.

3.4.4 Cleaner fish - pathogens

3.4.4.1 Concise description of cause

Cleaner fish are susceptible to a variety of viral, bacterial, fungal and parasitic diseases (Korsnes *et al.* 2017; VKM *et al.*, 2017; Brooker *et al.*, 2018; Powell *et al.*, 2018a). Cleaner fish can also carry pathogens, without displaying signs of infection; e.g. notifiable viruses have been detected in farmed lumpfish (Powell *et al.*, 2018a). 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.*, 2018a).

3.4.4.2 Concise description of possible effects

The endemic pathogen load on local wild fish could increase. New pathogens could be translocated or emerge that may affect wild (and farmed) fish.

3.4.4.3 Summary of how it is dealt with in different countries

How much does the significance of the issue differ between different countries

The issue applies to all species of cleaner fish, and is of consistent significance across those countries where cleaner fish are deployed.

An outbreak of the notifiable disease Viral Haemorrhagic Septicaemia (VHS) occurred in Scotland in 2012, in five species of wild-caught wrasse transported ca. 600 km and stocked into salmon net-pens (Hall *et al.* 2013). Containment areas were established, and the stocked wrasse were removed. The outbreak investigation found various species of wild fish were VHS-positive, but it was concluded that the pathogen was endemic and more likely to have spread to (rather than from) the farm stock.

An outbreak of a novel genotype of VHS occurred in west Iceland in 2015, in juvenile lumpfish being reared within a hatchery (Guðmundsdóttir *et al.*, 2019). The pathogen is thought to have been brought into the hatchery with wild-caught broodstock and then transmitted to neighbouring tanks. The virus caused external lesions and increased mortality. Containment measures included culling (with appropriate disposal) and disinfection of the facilities. Although Iceland produce lumpfish for export (Guðmundsdóttir *et al.*, 2019), there was no indication that this novel pathogen was spread outside the hatchery to other countries or regions within Iceland.

A novel ranavirus has also been isolated from lumpfish in the Faroe Islands, Iceland, Scotland and Ireland (VKM *et al.*, 2017; Guðmundsdóttir *et al.*, 2019), and a novel lumpfish flavivirus (LFV) has also been reported in Norway (VKM *et al.*, 2017). No information is available on the possible role of lumpfish translocation in the spread of these viruses.

Existing regulation

The control and management of pathogens in cleaner fish on farms falls under the same fish health regulations as those for the main stock (see Section 3.2 Parasite and pathogen transfer). Application of such regulations may, however, focus on the main stock and cleaner fish require additional consideration. For example:

- In Scotland cleaner fish are not permitted to be deployed with seawater rainbow trout, because the latter species is susceptible to VHS. In contrast, in Norway cleaner fish are used with seawater rainbow trout (Skiftesvik *et al.*, 2014).
- Although redeployment of surviving cleaner fish at the end of a production cycle would be considered an efficient use, such redeployment is typically prevented due to the potential for disease transfer (Brooker *et al.*, 2018).

Monitoring practices

The monitoring of pathogens in cleaner fish falls under the same regulations as those for the main stock being farmed (see Section 3.2 Parasite and pathogen transfer). However, the implementation of such regulations may focus on fish of farmed origin, and neglect wild-sourced fish.

EU aquatic animal health legislation (Council Directive 2006/88/EC) requires that farmed cleaner fish (and other aquatic animals) imported into, and moved between compartments within Europe, must undergo a health check. However, such health certification can only address known pathogens, and its accuracy will depend upon the examination methods. Following the VHS outbreak in Iceland in 2015, the health check was expanded to include VHSV (Guðmundsdóttir *et al.*, 2019).

In England, fishers temporarily holding live wild cleaner fish are now required to be authorized under aquatic animal health regulations as "dealers", meaning holding facilities are inspected and there is a requirement to report unexpected mortalities and health issues to the competent authority. However, the health status of the wild wrasse is not routinely monitored. In a research study assessing the health of wild wrasse being translocated from southwest England to Scotland, McMurtrie *et al.* (2019) recorded a range of protozoan and metazoan parasites. The pathogens identified did not cause immediate concern, but it was recommended that routine monitoring was introduced.

3.4.4.4 Emerging issues and knowledge gaps

Murray (2016) suggested that pathogen issues associated with the use of cleaner fish could be reduced by: disease surveillance, reducing mixing from different sources, and replacing wild-caught with hatchery-reared cleaner fish.

Riley *et al.* (2017) suggested that the pathogen status of wild wrasse should be examined. Korsnes *et al.* (2017) examined the prevalence of nervous necrosis virus (NNV) in wild wrasse (goldsinny, corkwing, ballan) in Norway and Sweden. They found an overall prevalence of 6.7%, and a high genetic variability. These results highlight the potential for translocation of virus strains by movements of wild wrasse (as well as the risk of introducing NNV into aquaculture).

For biosecurity reasons, surviving cleaner fish are not currently reused in subsequent salmonid production cycles. However, the reuse of wrasse has been discussed as it would reduce pressure on wild stocks (VKM *et al.*, 2017). The practice has potential to reduce the risk of pathogen introduction, but it may also increase the risk of interspecies pathogen transfer by extending the cohabitation period (Murray, 2016). The practice may be permitted in future if the risk of transmission can be minimized (VKM *et al.*, 2017).

Research and development to improve the health status of farmed cleaner fish is ongoing. Vaccines are being developed for the major diseases (Brooker *et al.*, 2018, Powell *et al.*, 2018a), but as with any species new to culture, there is a lag before introduction. The recent suggestion that wild lumpfish acquire immuno-protective mucus from kelp (*Laminaria*), which is absent in both hatchery and net-pen culture, further illustrates knowledge gaps with new species.

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4 Environmental impacts and recommendations for prioritized research – bivalve aquaculture

Various scientific reviews of bivalve aquaculture-interactions (Forrest et al., 2009; Keeley et al., 2009) have shown that the main ones are related to influences on pelagic communities, benthic communities, diseases, exotic species, genetic relations between cultured and wild bivalves, wild megafauna – such as birds and marine mammals, and sensitive habitats (Figures 4.1 and 4.2). Moreover, such effects may be considered as nearfield (10s of m) and far-field (> 100 m) effects, depending on the spatial scale on which effects are most apparent and may operate at both scales, depending on variable of concern (Weitzman et al., 2019). Nearfield impacts of modified sedimentation regimes related to suspended bivalve culture and related biodeposition on benthic conditions (infaunal communities and related biogeochemical proxies, such as sulphides) are well known (McKindsey et al., 2011); effects on local macrofaunal communities, particularly scavenging and predatory species, including megafauna, are known to some extent (Callier et al., 2018; Barrett et al., 2019) although the ecosystem-level effects of this and on the individual animals that are attracted to potential food sources or habitats are poorly known (Sardenne et al., 2019). Likewise, impacts of bivalve culture on phytoplankton communities are well known (Hulot et al., 2020) and form the basis of most studies on carrying capacity (Grant and Pastres, 2019) whereas impacts on zooplankton and other pelagic groups are less well-known (Hulot et al., 2020). Interactions between farmed bivalves and wild bivalves with respect to pathogens are understudied, although, together with aquatic invasive species (AIS), they form the basis of many Introduction and Transfer screening protocols (Fernández Robledo et al., 2018; Castinel et al., 2019). The implications of bivalve farming as vectors and habitats for AIS are well-recognized, as are the risks associated with the introduction of bivalves for aquaculture, whether related to hitchhiking species or to escapes of farmed bivalves to the surrounding environment (McKindsey et al., 2007; Padilla et al., 2011). Consequences of escapes of reproductive materials from farmed bivalves on the genetic integrity of local species are largely unknown (Leggatt et al., 2010; Hedgecock, 2011). Sensitivity of ecologically important species, such as seagrass, to nearfield effects of bivalve culture are known to some extent whereas far-field effects remain largely hypothetical (Dumbauld and McCoy, 2015; Ferriss et al., 2019). Below, we expand briefly on these issues and discuss how different countries address them, the rules and regulations that are used to that end, and emerging issues and priorities.

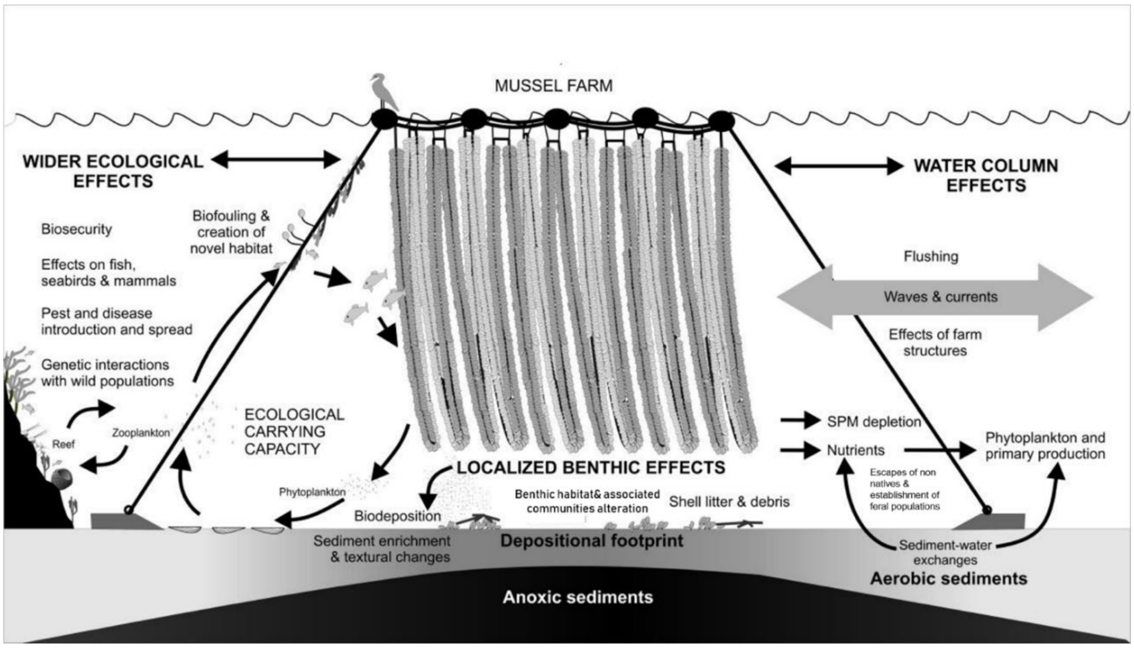

Figure 4.1. Illustration of environmental impacts of suspended bivalve farming in New Zealand (taken from Keeley *et al.*, 2009)

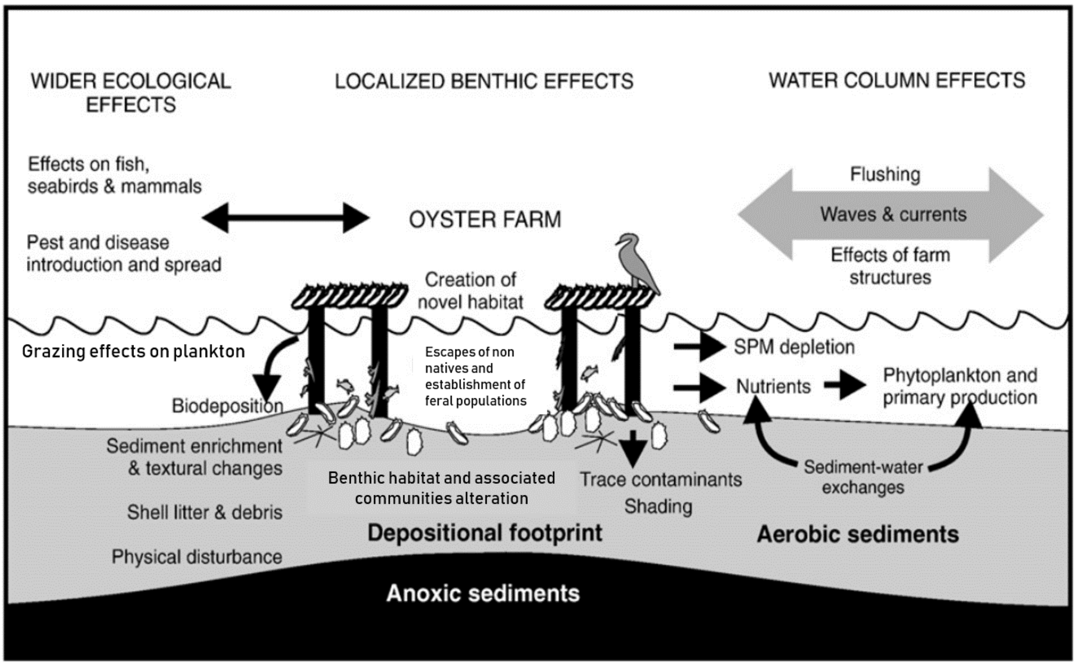

Figure 4.2. Illustration of environmental impacts of off-bottom bivalve farming in New Zealand (taken from Forrest *et al.*, 2009)

4.1 Benthic impacts

There are two main culture methods for bivalve molluscs in intertidal and subtidal areas; off-bottom and on-bottom. Off-bottom culture includes suspended culture, utilizing rafts or long-lines in subtidal areas and the stake/pole and rack methods in intertidal areas. Stake or pole culture is used for mussel culture and consists of poles that are driven into the seabed with some space between the poles to ensure water exchange and facilitate husbandry. In France, these pole farms (bouchot culture) can consist of 15 000 – 20 000 poles. Rack culture uses structures fixed on the seabed that support ropes, plastic bags, or cages with mussels/oysters suspended above the seabed. Rack culture is most common in oyster cultivation (trestle culture) but is also used in mussel production in some Asian countries. The trestles are installed at the low water mark and consist usually of double rows which are separated by lanes to facilitate husbandry and harvest by tractor. Trestle culture can cover large areas in the intertidal zone.

On-bottom culture is when the bivalves are cultured directly on or in the sea-bed. Seed can either be collected on-site by spat collectors or it can be collected elsewhere and transplanted to the cultivation site. Netting, boxes, trays or fences can be used to protect the farmed bivalves from predators and from being flushed away during rough weather. On-bottom culture can be located in shallow tidal areas (clams, oysters and mussels) or in deeper areas (scallops). Husbandry and harvesting is done mechanically, by hand, or by divers, depending on location and depth. On-bottom culture can cover large areas, with the dense oyster reefs and mussel beds in the Wadden Sea being well-known examples.

The benthic impacts of bivalve shellfish farming are related to the deposition and accumulation of shell litter and live shellfish (fall-off) and sedimentation of organic-rich biodeposits comprised of faeces and psudofaeces (Ministry for Primary Industries - Manatū Ahu Matua, 2013). These seabed deposits may smother benthic communities, alter the physical properties of the sediments, and reduce the water flow and exchange (Ministry for Primary Industries - Manatū Ahu Matua, 2013). The impacts of fall-off from subtidal off-bottom aquaculture, infaunal community changes due to biodeposition, and hydrodynamic changes are discussed below.

4.1.1 Fall-off under structures - Longline and raft culture

Concise description of cause

Through the rope and raft culture of bivalves, live shellfish, shell debris and fragments of farm equipment (such as rope, bags, and sticks depending on the type of culture) may become dislodged and accumulate on the benthos directly below farm structures (Solomon and Ahmed, 2016). This may occur during periods of rough weather or through poor husbandry practices.

Concise description of effects

Accumulations of material beneath shellfish farms from fall-off can provide potential habitats for fouling organisms and mobile biota (Solomon and Ahmed, 2016). However, this build-up of debris may lead to decreased water flow across bottom sediments, potentially increasing local sedimentation (de Jong, 1994). These deposits may smother benthic fauna and change benthic community structure.

4.1.2 Biodeposit-related infaunal community changes - Trestle culture and bottom culture

Concise description of cause

Filter-feeding bivalves remove seston from the water column. A portion of what is captured is excreted as faeces whilst another part is sorted and rejected without being ingested and is referred to as pseudofaeces. Faeces and pseudofaeces are known collectively as biodeposits and may enrich benthic habitats (ICES, 2014). Suspended or off-bottom bivalve culture can result in increased organic loading within and in the vicinity of aquaculture sites as released biodeposits can settle relatively quickly to the bottom (Dame, 1996; Newell, 2004). The amount of biodeposits produced and the rate at which they settle is highly variable and dependent on bivalve species, diet and size (e.g., Weise *et al.*, 2009) but generally settlement rates fall within the range of approximately 0.25 to 3 cm sec^{-1} (McKindsey *et al.*, 2011).

Mechanical husbandry and harvest methods is considered to be the main cause of effect on infaunal communities associated with bivalve culture in intertidal areas. Dredge harvest of on-bottom cultures disturbs the sediments and the infauna, attracting predators to feed on the exposed species (Toupoint *et al.*, 2008). Also, the disturbance of the sediment allows wash out of fine particles which may change sediment grain composition and thus infaunal community composition (Piersma *et al.*, 2001). Over time, sediment will be restored and it is assumed that there are few long-time effects on infauna caused by bivalve harvest practices (Kaiser *et al.*, 1998).

Concise description of effects

Although there is limited information on effects on infauna by off-bottom and on-bottom bivalve culture in intertidal areas, most studies on organic enrichment of the seabed from shellfish farming have concluded that the effect is small, and much less than that caused by finfish farming (Crawford *et al.*, 2003; Callier *et al.*, 2018). In general, benthic structures provide considerable surface area for sessile and other hard substrate-associated organisms that are not normally found on soft sediment bottoms (Callier *et al.*, 2018). Thus, in mudflat areas previously inhabited by soft bottom species, on-bottom cultivation of bivalves may result in a shift to hard-bottom communities. On-bottom bivalve culture provides a three-dimensional structure for many invertebrates, both benthic and infaunal, and serves as both a food source and habitat that may have a positive effect on local biodiversity (Tsuchiya and Nishihira, 1985; Dittman, 1990; Seed and Suchanek, 1992; Reise, 2002; Thiel and Ullrich, 2002; Gutiérrez *et al.*, 2003).

Comparing on-bottom mussel beds and control sites (natural mussel beds), Murray *et al.* (2007) found that the infauna community changed and that the species diversity was decreased on the culture site. In spite of these findings, Murray *et al.* (2007) refused to conclude that the decreased biodiversity was only negative since "*The removal of seed mussel from an intertidal site may allow underlying fauna to prosper in the newly exposed surface sediments, whereas the newly created subtidal mussel structure and associated sediment provides increased substrate for many species*." In a study of scallop bottom culture in Peru, Kluger *et al.* (2016) concluded that the high-density scallop beds had a negative impact on biodiversity, although there were also some positive effects. Overall, results are mixed as to the overall net positive or negative effect of on-bottom bivalve culture on infaunal communities.

Other potential impacts of bivalve bottom culture include local oxygen depletion due to increased organic loading (i.e., biodeposition). High rates of biodeposition may increase microbial activity and reducing sediment conditions, leading to endobenthic communities with low diversity dominated by opportunistic species such as capitellid polychaetes and oligochaetes (Ysebaert *et al.*, 2009).

4.1.3 Hydrodynamic changes

Concise description of cause

Bivalve aquaculture farm structures, such as ropes, anchors, and bags, can cause drag and alter hydrodynamic processes within an area, redirecting water flow and generating turbulence (National Research Council, 2009; McKindsey, 2011; McKindsey *et al.*, 2011; Cranford *et al.*, 2012) (Figure 4.3). The presence of these structures may reduce current speeds within areas and if they are at or near the surface, wave dampening can occur (Ministry for Primary Industries - Manatū Ahu Matua, 2013).

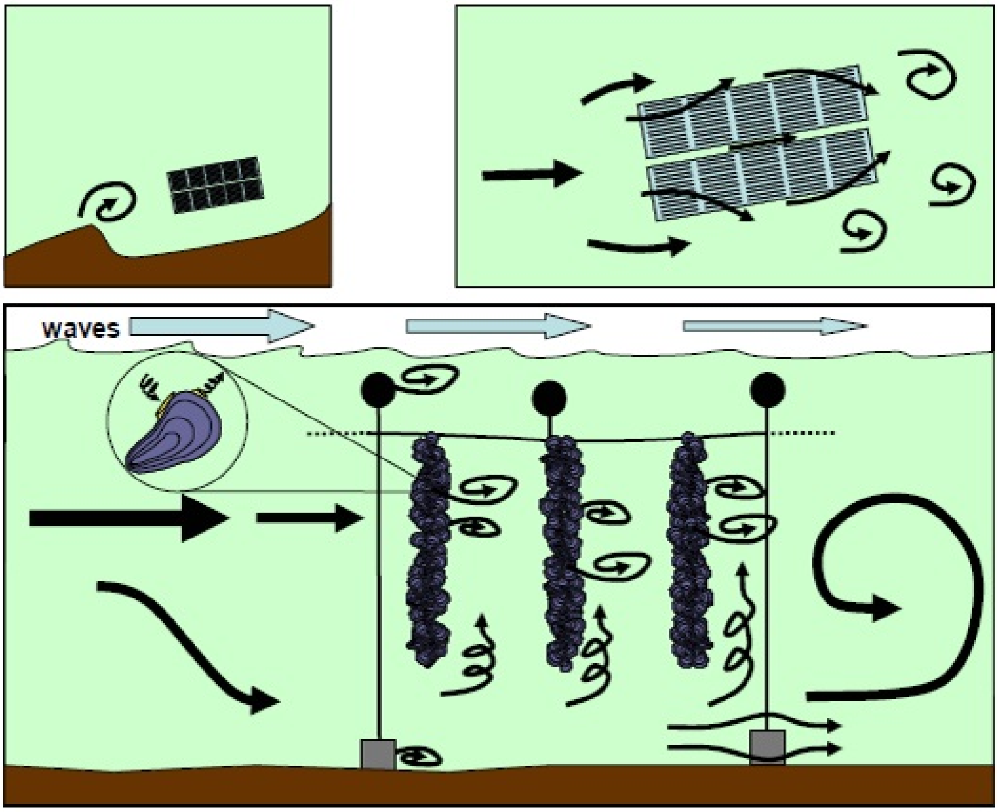

Figure 4.3. Taken from McKindsey 2011.

Concise description of effect

As described above, the physical presence of aquaculture structures may affect local hydrodynamics. Aquaculture structures can alter the direction of flow within an area, reduce current speed, and dampen wave action (Forrest and Hopkins, 2017).

In the case of subtidal or on-bottom culture, these effects are believed to be minimal, whilst the impacts of subtidal longline culture and intertidal rack/trestle culture are thought to be intermediate (Forrest and Hopkins, 2017). Longline suspended oyster culture can increase retention time within culture sites (Makita and Saeki, 2004) and the presence of aquaculture structures can impact flushing times within entire bays (Lo *et al.*, 2008; Plew, 2013).

The extent to which hydrodynamics are modified within an area depends on the characteristics of the aquaculture structures and the benthic habitats beneath them (Forrest *et al.*, 2009). These effects are strongest within the farmed area and decrease with increasing distance from the aquaculture site (Ministry for Primary Industries - Manatū Ahu Matua, 2013).

4.1.4 Summary of how benthic Issues are dealt with in different countries

Of the countries who supplied information for input into this document, only Canada and China identified biodeposits under culture structures and the impacts of infaunal community changes as a knowledge gap. The UK (Northern Ireland) was the only country to identify changes in hydrodynamics as a knowledge gap. Norway highlighted the requirement for Environmental Impact Assessments for shellfish culture whilst the UK (England and Scotland) and China identified the need for the development of carrying capacity models.

No country identified specific regulations for potential benthic impacts of bivalve culture. However, within the UK and Ireland, if a proposed new aquaculture site is located within or adjacent to a site designated under the Habitats or Birds directives then a Habitats regulations assessment must be undertaken to establish the potential impacts of aquaculture activities. Furthermore, proposed aquaculture sites that are proximate to sensitive habitats and beyond the boundaries of protected sites (e.g., Natura 2000 sites) are also subject to risk assessment.

Considerable research has been conducted in Canada on the benthic impacts of organic biodeposition from shellfish culture. A recommended monitoring framework was developed and published by the WGMASC (Cranford *et al.,* 2012). Additional knowledge is needed on the selection of applicable impact indicators and thresholds.

Extensive work has been undertaken within Northern Ireland on the development of carrying capacity models for shellfish culture through the Sustainable Mariculture in Northern Irish Lough Ecosystems (SMILE) initiative (Ferreira *et al.,* 2007). These models are currently utilized by the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland to assess applications for new shellfish aquaculture licences.

Whilst no country identified specific regulations for benthic impacts resulting from bivalve culture, some, such as Canada, Denmark and the UK (Northern Ireland) indicated that monitoring of benthic sediments was often required.

Emerging issues and prioritized research

- The requirement for Environmental Impact Assessment
- Ecological carrying capacity models
- Lack of information on the impacts of different methods of bivalve culture within different environments (sea loughs, open water etc.)

4.2 Water column impacts/ecosystem services

As filter-feeders, bivalve shellfish are intrinsically linked to the natural environment and interactions with the water column. Plankton are extracted from the water column and wastes are also released back into the environment which can then impact ecosystem structure and functioning. These impacts can have negative and positive consequences. The issues have been divided into separate sections, focusing on phytoplankton and zooplankton.

4.2.1 Phytoplankton removal, top-down control of eutrophication

Concise description of cause

Bivalves are filter-feeders and they extract their food from the water column. Production is determined by the natural environment. However, this means there is a risk that farm production could decrease or fail if food resources are depleted (Petersen *et al.*, 2008), with consequences for the wider foodweb. Phytoplankton are typically the primary food source for farmed bivalves. However, in seasons when phytoplankton levels are lower, zooplankton and detritus play a more important role (Ezgeta-Balić *et al.*, 2012). In addition to removing phytoplankton from the water column, shellfish release nutrients into the water, resulting in complex ecosystem interactions due to simultaneous top-down and bottom-up control on phytoplankton (Cranford *et al.*, 2007). Consequently, it is difficult to generalize impacts between locations, as the amount of phytoplankton removed from the water column by shellfish will depend of coastal conditions and seasonality as well as farm size and culture practices (Petersen *et al.*, 2008; Strohmeier *et al.*, 2008).

Concise description of effects

Bivalves are filter-feeders and impact the water column via filtration, grazing and excretion (Gallardi, 2014). The impacts of phytoplankton removal from the water column have been well documented (Grant *et al.*, 2008; Petersen *et al.*, 2008; Strohmeier *et al.*, 2008; Cranford *et al.*, 2011). If grazing pressure exceeds gross planktonic production and renewal then there will be a depletion of plankton abundance and biomass, this in turn affecting food availability for the shellfish, as well as the wider foodweb and ecosystem (Smaal and van Duren, 2019; Hulot *et al.*, 2020). It is important to note that local conditions will influence the overall effect and it can be difficult to generalize effects (Prins *et al.*, 1998). Water column interactions as nutrient turnover exerted by mussel (*Mytilus edulis*) farming is different in deep oligotrophic systems (fjords) and shallow eutrophic areas (Jansen *et al.*, 2011). In the oligotrophic environment there is also significant seasonal fluctuations in regeneration processes and influence of fauna associated with mussel cultures. A lower fraction of nutrients is allocated to defaecation processes in oligotrophic fjord systems than in shallow eutrophic areas, likely caused by the low food concentrations (Jansen *et al.*, 2012). To assess carrying capacity, there is a need to understand the water column and the biogeochemical components that influence the flux of nutrients and primary production and how this is used by bivalves (McKindsey *et al.*, 2006).

Shellfish can regulate nutrients in the water column, acting as a bioremediator, providing an ecosystem service (Petersen *et al.*, 2019; van der Schatte Olivier *et al.*, 2020). High nutrient levels leading to phytoplankton blooms and coastal eutrophication are a major issue in many parts of the world. In addition to ecosystem service provision through food production, due to removal of phytoplankton from the water column, shellfish provide top-down control as a regulating ecosystem service and can reduce risks of phytoplankton blooms and eutrophication (van der Schatte Olivier *et al.*, 2020).

There is the potential for shellfish culture to be used in nutrient credit trading programmes, offsetting other industries and sectors (Ferreira and Bricker, 2016).

Summary of how phytoplankton removal is dealt with in different countries

The significance of the issue will depend on the species, system and the location of shellfish aquaculture, as well as the scale of operations and density of farms in particular areas. There appears to be no specific regulation on phytoplankton removal, but there may be an assessment of the production and ecological carrying capacity prior to establishing a site as part of the planning and licensing process. In each country, this is covered by the regulations which govern aquaculture development. Carrying capacity models are used in some areas. For example, in the USA, carrying capacity models contribute to environmental reviews which are then assessed by state agencies and the U.S. Army Corp of Engineers to determine if a permit or expansion should be granted.

Few countries appear to implement monitoring programmes for assessing phytoplankton removal by shellfish. In Ireland, monitoring may be required as part of the licence conditions, but this will depend on the farm. Under the EU Water Framework Directive, monitoring of physico-chemical (incl nutrients) parameters may be carried out in shared waterbodies, though not specific to shellfish aquaculture. In China, the fishery administrative departments are responsible for environmental monitoring. However most other countries focus on monitoring for human safety rather than environmental impact.

Emerging issues and prioritized research

There are several knowledge gaps and emerging issues. Several countries highlighted the need for data and new or improved carrying capacity models (e.g. China, UK, USA). Furthermore, the different systems and species cultured each have their own knowledge gaps and research needs. This can be an issue for countries with a diverse sector such as China, where there are over 40 species of molluscs cultured. On the other hand, in Norway, a country with a small shellfish sector, there are knowledge gaps about the ecological interaction between suspension-feeders and the environment at larger scale production.

4.2.2 Zooplankton removal, top-down control of plankton

Concise description of cause

Bivalves feed by filtering plankton and detritus from the water column. In the shellfish aquaculture context, although most work to date has concentrated on the effects of farmed bivalve grazing on phytoplankton (Dame, 1996; Cranford, 2019), bivalves may also be important predators on zooplankton (Davenport *et al.*, 2000; Lehane and Davenport, 2004; Lonsdale *et al.*, 2007; Maar *et al.*, 2008), including in shellfish farms (Zeldis *et al.*, 2004; Lehane and Davenport, 2006; Maar *et al.*, 2008), although this effect has not been widely evaluated (McKindsey *et al.*, 2011; Filgueira *et al.*, 2015). All types of zooplankton seem to be susceptible to predation by farmed bivalves, including both holoplankton and meroplankton, with the composition of ingested zooplankton typically mirroring that found in the surrounding natural environment (Ezgeta-Balić *et al.*, 2012). For example, Lehane and Davenport (2006) found farmed blue mussels to consume calanoid and harpacticoid copepods, crustacean nauplii, barnacle cyprids, bivalve larvae, amphipods, and ostracods, Peharda *et al.* (2012) observed tintinnids, copepod nauplii, copepods, gastropod and bivalve larvae, and unidentified eggs in the stomachs of 4 bivalve species, and Maar *et al.* (2008) suggested that farmed Mediterranean mussels consume copepodites and barnacle, gastropod, and polychaete larvae. With the exception of some very large species, such as larval lobster (Gendron *et al.*, 2003; Sonier *et al.*, 2018), it also seems that farmed bivalves may consume a wide size range of zooplankton. For example, although Lehane and Davenport (2002) showed that 3 species of bivalves consumed a wide variety of zooplankton, there was a preponderance of smaller individuals in the bivalve stomachs when sampled, perhaps reflecting differences in zooplankton escape speeds that favour the capture of smaller plankton (Ezgeta-Balić *et al.*, 2012), whereas Lehane and Davenport (2006) found farmed mussel to consume zooplankton (amphipods) up to 6 mm in length. Clearly, farmed bivalves may consume a wide variety of zooplankton.

Concise description of effects

Given the clear capacity of farmed bivalves of consuming zooplankton and the potential scale of farm operations in some areas, it is clear that knowledge of the impact of such grazing is required to promote sustainable aquaculture (Ezgeta-Balić et al., 2012). At the basic level, predation on zooplankton by farmed bivalves may alter the trophic structure of the pelagic foodweb (Prins et al., 1998) and energy transfer to higher trophic levels, potentially impacting larval and thus larger fish and other species (Gibbs, 2007). (Note, however, that farmed bivalves may, in some way, replace some of the ecological roles of the zooplankton on which they prey as they become the major grazers in a system (Jiang and Gibbs, 2005)). Farmed bivalves may impact both holoplankton and meroplankton species. Effects on holoplankton may be greatest as plankton renewal times are mostly a function of water renewal times, although this effect has not been evaluated for bivalve farm sites to date (Hulot et al., 2020). In contrast, much meroplankton is likely produced locally and may be replaced on an ongoing basis. Despite this, Lehane and Davenport (2002) suggests that larviphagy on a number of taxonomic groups is evident and Peharda et al. (2012) suggests this impacts the availability of natural spat for recruitment to local environments with consequent impacts for farmed and natural populations. There is little evidence of cascading trophic effects in natural environments, although several modelling studies have suggested this to be the case. For example, Guyondet et al. (2014) suggest that farmed mussels will have the greatest effect on zooplankton biomass (relative to NH4, phytoplankton, and detritus, while admitting that the effect may be an artefact of the model structure). Byron et al. (2011) suggest that farmed oysters and zooplankton compete for primary production (i.e. phytoplankton) such that a reduction in zooplankton levels would benefit farmed (and wild) oyster growth rates as well as other filter-feeders. In a worst-case scenario, Jiang and Gibbs (2005) suggest that extreme predation on zooplankton may collapse a system to a simple nutrient-phytoplankton-bivalve culture-detritus system with other trophic levels being extinct. It must be kept in mind that potential ecosystem effects remain speculative as there is a paucity of data to support such predictions (Hulot et al., 2020).

Summary of how it is dealt with in different countries

The only country to identify this as a knowledge gap was Canada. Norway highlighted the need for a better understanding of "Ecological interaction(s) between suspension-feeders and the environment at larger scale production" and the UK (England and Scotland) and China identified ecological carrying capacity modelling as a knowledge gap.

No country highlighted specific water column metrics for use in regulating the industry.

Emerging issues and prioritized research

Although farmed bivalves clearly feed on zooplankton, effects due to grazing on bivalves remain poorly studied. Cascading effects of this predation on wild species, including those with meroplanktonic stages that may be directly impacted, are largely speculative.

4.3 Pathogens

Bivalves can be both a host and a vector of micro parasites such as *Marteilia*, *Bonamia, Microcytos* and *Perkinsus* species (Brenner *et al.,* 2014). Several working groups within ICES, such as the Working Group on Application of Genetics in Fisheries and Aquaculture (WGAGFA) and the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), are comprised of experts who look specifically at Bivalve pathogens. It is for this reason that this subject is not discussed in detail within this document.

4.4 Ecological impacts

Given the large number of organisms used and placed into the natural environment for bivalve culture, it is clear that this may impact wild populations fairly directly. This may be via the introduction of species that are not a natural part of the local environment (i.e. through the use of non-native species for culture purposes), which may escape and become a functional, and at times, important, part of the surrounding ecosystem. Or, it may be due to the removal of substantial numbers of wild organisms through harvesting of wild spat/juveniles, as is practised in, for example, Ireland and Spain for mussel culture. These issues have been divided into separate sections, focusing on non-native species establishing feral populations and overfishing of natural seed stocks.

4.4.1 Non-native species establishing feral populations

Concise description of cause

Over the years, non-native species have been introduced to many locations for aquaculture purposes. These species often have specific characteristics or strong markets that make them an attractive aquaculture species even in locations where they would not be found naturally. However, their introduction can result in negative consequences, especially if feral populations establish beyond the aquaculture farm (McKindsey *et al.,* 2007; Padilla *et al.,* 2011). Bivalve aquaculture has become the largest sector of the Chinese mariculture, accounting for about 90% of the total molluscan production in 2015 (Mao *et al.,* 2019). Approximately 70 different bivalve species are used, many of which are introduced species (Mao *et al.,* 2019), although information about the ecological impact of these introductions is scarce. In other ICES countries, one of the most well-known non-native shellfish species is Pacific oyster (*Crassostrea gigas*), which originates in coastal waters of Japan and Southeast Asia but is now found throughout the world, having been introduced in many areas for aquaculture (Faust *et al.*, 2017; Shelmerdine *et al.*, 2017). It was introduced in many temperate locations on the assumption that temperatures were too low for reproduction. However, it has now become established in many countries (Diederich *et al.*, 2005; Laugen *et al.*, 2015), likely due to having a wider tolerance than previously thought and increasing sea temperatures (Strand *et al.,* 2011).

Concise description of effects

Non-native shellfish may displace native species and modify habitats and ecosystems, although the effects will depend on the introduced species, the ecosystem that they have been introduced to, and their ability to establish (Herbert *et al.,* 2016). In the case of Pacific oyster, under suitable conditions, it can establish and colonize relatively quickly, leading to changes in the species composition of the natural system (Smaal *et al.,* 2005; Smaal *et al.,* 2009). Initial and short-term changes will affect lower trophic species, but there may also be long-term changes that shift the natural system to a new functional state, potentially affecting the food available for birds and mammals (Smaal *et al.,* 2005). This may have implications for sensitive habitats and protected areas. For Member States of the European Union, it is recognized that invasive species are a potential risk to achieving good ecological status in the EU Water Framework Directive (Herbert *et al.,* 2016).

Summary of how it is dealt with in different countries

The significance of the issue will depend on the country, although all recognize that invasive species can be a problem. Most countries have regulations on the use of non-native species for aquaculture. This is often covered in the overall fisheries/aquaculture acts that governs the sector and are overseen by the Government departments responsible for the sector (e.g. Directorate of Fisheries in Norway, Danish Fisheries Agency and Ministry of Environment, Fisheries and Oceans Canada). In the case of Pacific oyster, there are differences between countries in how they classify the species due to its economic importance since it was first introduced decades ago. In many ICES countries, Pacific oysters are one of the highest produced species (by volume and value), and the related socio-economic benefits are considerable. Most countries have controls on introduction, often managed through the planning and licensing process. The producer and/or responsible authorities will consider the infrastructure and equipment, operational and biosecurity practices at the farm and then this can be used to determine if the shellfish are likely to be confined and the risk of spread. Spatial planning and zoning can also be used to assess and identify areas where Pacific oyster production could be possible and others where it should be restricted. If there is a risk of naturalization, then some countries such as Ireland recommend the use of triploid oysters. In Norway, oyster beds will be removed if they are in conflict areas. Although mechanical control and removal of oysters is possible in some areas, it is not possible or feasible in others, e.g. areas in The Netherlands, due to the high densities there (Herbert *et al.,* 2016).

Some countries (e.g. Ireland, Norway) have monitoring programs to map the occurrence of Pacific oysters. There are also several ongoing scientific studies examining the establishment of feral Pacific oyster populations, particularly in Scandinavian counties where it was originally thought the species would not be able to spread (Strand *et al.,* 2011; Laugen *et al.,* 2015; Anglès d'Auriac *et al.,* 2017; Faust *et al.,* 2017).

Emerging issues and prioritized research

There are several key knowledge gaps about non-native species and the establishment of feral populations, particularly around the interactions with native species, impacts on the natural environment, and effective control measures. There is also a need to establish clear policy around use and control of native species and how 'harm' is defined. Over the next few years and decades, new challenges will emerge especially due to climate change and the potential for species to increase their range and spread into new areas (Mao *et al.,* 2019).

4.4.2 Overfishing of natural seed stocks

Concise description of cause

In many countries, such as the UK, Ireland and the Netherlands, bottom culture of blue mussels *Mytilus edulis* is reliant on the natural settlement of mussel seed beds (Brown *et al.,* 2006; Maguire *et al.,* 2007; Bord Iascaigh Mhara, 2008). Recent years have seen a major imbalance between seed demand and availability.

Seed mussels tend to be concentrated in distinct areas in large numbers (Shellfish Association of Great Britain, 2008). As seed beds develop, dead shells, silt and pseudofaces build up a layer of 'mussel mud' beneath the seed (Kaiser *et al.*, 1998; Shellfish Association of Great Britain, 2008). This unstable layer causes the seed mussels to detach their byssal threads and they can therefore be dredged from the surface of the mussel mud with minimal disturbance to the underlying substratum (Kaiser *et al.*, 1998; Shellfish Association of Great Britain, 2008).

These seed beds are then licensed by government departments and fished by the aquaculture industry (Shellfish Association of Great Britain, 2008). These seed mussels are then relaid onto aquaculture sites for ongrowing to marketable size (Kaiser *et al.*, 1998).

Settlement within European seed mussel beds is highly variable between years (Maguire *et al.*, 2007; Bord Iascaigh Mhara, 2008; Scottish Aquaculture Research Forum, 2014; Jessop, 2015), with poor recruitment and overfishing (Jessop, 2015) believed to be the main causes.

Studies into alternative sources of seed mussel have investigated spawning and larval culture in hatcheries (Bord Iascaigh Mhara, 2008; Jessop, 2015). Whilst it is feasible to produce mussel spat in hatcheries, the cost of doing so renders this option uneconomical (Bord Iascaigh Mhara, 2008; Shellfish Association of Great Britain, 2008; Scottish Aquaculture Research Forum, 2014).

Concise description of effects

The three-dimensional hard substrate structure of mussel beds provide shelter for mobile epibenthic species and habitats for hard substrate epibenthic species (Craeymeersch *et al.*, 2013). Craeymeersch *et al.* (2013) identified short-term impacts of seed mussel fishing in the Wadden Sea on the composition and densities of associated macrobenthic communities. After seed fishing, species densities were lower in the fished areas than in the unfished areas. The incidental capture of bycatch species during seed fishing may have an impact on the sustainability and population dynamics of these species (Bord Iascaigh Mhara, 2008).

As seed mussel beds occur in discreete areas, the physical disturbance caused by dredging is confined to relatively small localized areas of the seabed (Kaiser *et al.*, 1998). The seasonal nature of seed settlement and fishing allows for periods of up to a year for the recovery of the surrounding ecosystems from any negative impacts of dredging (Kaiser *et al.*, 1998; Shellfish Association of Great Britain, 2008). Kaiser *et al.* (1998) noted that if seed mussel beds weren't exploited they would be destroyed by winter storms or ravaged by starfish predators.

These seed mussel beds can also provide an essential food resource for internationally important species of birds (Jessop, 2015). Overexploitation of mussel seedbeds in the Netherlands caused declines in eider duck and a reduction in the breeding success of oystercatchers who utilized these mussels as a food source (Kaiser *et al.*, 1998; Bord Iascaigh Mhara, 2008).

Summary of how it is dealt with in different countries

The significance of the impacts varies between countries. However, all countries who provided input (Canada, Denmark, Ireland, the UK (England, Scotland, Northern Ireland), and the USA) highlighted national legislation which is in place to regulate the collection of wild seed. For some countries, this legislation includes Fishery enforcement and monitoring of landings (UK – England and Northern Ireland). In Ireland, monitoring may be specified within seed fishing areas.

Within the UK (England and Northern Ireland) and Ireland seed mussel stock assessment surveys are undertaken annually, to identify and quantify seed mussel beds, and to inform government departments of the nature and location of these beds so that decisions can be made as to the opening of seed fisheries.

Emerging issues and prioritized research

The main knowledge gap highlighted in relation of seed mussels is the unexplained interannual variation in seed settlement and availability. In addition, the broader decline of wild mussel stocks in coastal regions of Ireland is as yet unexplained and may be linked to the variable recruitment highlighted above.

4.5 Interaction with wild species

Interactions between shellfish aquaculture structures with attendant activities and wild animals is an important consideration when licencing and managing culture operations in marine environments. The structures can be an attractant to any number of species (Callier *et al.*, 2018) or an inadvertent hazard. The activities can present a level of disturbance that may impact species at the individual and population level.

Society has placed a particular value on certain species and habitats, affording them particular importance and protection. These include certain species of birds and mammals that may be afforded a certain protection given their conservation status – e.g. those on the IUCN Red List with a status of "Near Threatened" or poorer (Price *et al.*, 2017). Likewise, certain habitats, such as maerl and seagrasses (Hall-Spencer *et al.*, 2008; Fisheries and Oceans Canada, 2009) are considered to have greater habitat value than others and may thus be afforded greater consideration and protection.

These issues as they relate interactions between shellfish culture operations, specifically to marine mammals and birds and to mearl and seagrasses, are presented below. Mammals and birds are considered primarily because of the conservation importance of many of these species in most jurisdictions and that they are highly visible and broadly considered as charismatic fauna which are subject to considerable public scrutiny, more so than other taxonomic groups.

4.5.1 Protected species of marine mammals and birds

Concise description of cause

Marine Mammals: Potential pressures resulting from mariculture operations acting on marine mammals are likely varied yet, can be broadly summarized into the following categories:

- Habitat exclusion: whereby structures may result in a barrier to movement of species.
- Disturbance: ancillary activities at sites increase the risk of disturbance to species at haul-out sites (e.g. resting, breeding and/or moulting) or in the water.
- Entanglement: Entanglement of species from ropes or material used on structures or during operation of farms or during fishing.
- Ingestion of waste material used on farm.

It should be noted that direct demonstrations of many of these impacts are rare, and in most cases, potential effects are therefore predicted from the best existing information. Furthermore, none of the studies published to explore impacts on marine mammals and, for example, Harbour

Seal, were specifically designed to detect ecological impacts on this species (Becker *et al.*, 2009; National Research Council, 2009; Becker *et al.*, 2011). Even where studies have been carried out around shellfish farms, uncertainty over spatial and temporal variation in both the location of structures (Watson-Capps and Mann, 2005) and levels of disturbance (Becker *et al.*, 2009; Becker *et al.*, 2011) constrain the conclusions that can be drawn about the impacts of mariculture on critical life-history features such, as marine mammal reproduction and foraging.

Mariculture structures can provide shelter, roost, or haul-out sites for birds and seals (Roycroft *et al.*, 2004). There has been no targeted research conducted in similar ecosystems that has directly assessed the impact of this type of aquaculture on harbour seals or indeed any other seal populations. There has, however, been considerable research on short-term responses of harbour seals to disturbance from other sources, and these can be used to inform assessments the potential impacts of disturbance from aquaculture activities.

Displacement of pinnepeds and birds from areas may also result from disturbances attributable to the activities of mariculture workers (Becker *et al.*, 2009; Becker *et al.*, 2011; Gittings and O'Donoghue, 2012; Gittings and O'Donoghue, 2016). This disturbance may be caused directly by the presence of workers on intertidal areas. However, while disturbance from shellfish culture operations have been observed to influence the distribution of seals within a sheltered embayment, no inference can be made on the effect on broader population characteristics of harbour seals from this study (Becker *et al.*, 2011).

Given the presence of subtidal fixed structures associated with the suspended subtidal culture of shellfish operations (i.e. longlines), there is a possibility that their presence may act as a barrier restricting the range and movement of the species within critical habitat. Notwithstanding, interactions between dolphin and floating structures used in shellfish culture (rafts) were assessed by Díaz López and Methion (2017), who concluded that shellfish farms appeared to have a positive impact on dolphin occurrence, with increased bottlenose dolphin occurrence at mussel farm locations and in waters close to the aquaculture zones. The structures may act as fish aggregation devices which in turn might benefit the dolphin.

Birds: Largescale bivalve aquaculture could, theoretically, have impacts on ecosystem functioning and reduce the abundance of food resources for waterbird species. This could occur as a result of reduced recruitment (due to direct consumption of eggs and larvae by the cultured bivalves), and/or through indirect foodweb effects (e.g., consumption of organic matter by the cultured bivalves that would have otherwise been available to support other species). We describe these potential impacts as ecosystem effects as they are not spatially restricted to the areas in the vicinity of the aquaculture sites, but could affect the whole ecosystem.

Habitat and disturbance impacts

Potential negative impacts to bird species have been identified where the activity may cause negative impacts to prey resources and/or cause disturbance impacts, where there is evidence of a negative response to the activity by the species from previous work, and/or where a negative response is considered possible by analogy to activities that have similar types of impacts on habitat structure and/or by analogy to ecologically similar species.

Detailed research has been conducted to directly assess the potential impacts of oyster trestle cultivation on a range of shorebird species (Gittings and O'Donoghue, 2012; Gittings and O'Donoghue, 2016). These studies demonstrated that the majority of shorebirds showed a strong negative response to oyster trestles and culture activities. Some species demonstrated neutral /positive responses to the presence of trestles. More recent reports have identified neutral interactions between intertidal shellfish culture operations and habitat use by birds (Maslo *et al.*, 2020). All studies define disturbance by operators as the primary source of impact.

Concise description of effects

(from Price et al., 2016)

- Habitat exclusion for mammals and birds can range from low- to high-risk, depending upon the location and density of shellfish farms.
- Among cetaceans, the highest risk from mussel farms is to the baleen whales because they may have low ability to detect farms and to species (e.g., humpback whales) or individuals which roll when entangled.
- Toothed whales are considered less likely at risk, presumably because echo-locating abilities allow them to perceive the farm structures and avoid or navigate through them.
- Seabirds and sea turtles are at risk for interactions with and entanglement in farm gear. Some management practices implemented for marine mammals may also benefit these species.
- Marine debris originating from aquaculture facilities poses risks for entanglement and ingestion, but the extent of the contribution of marine farms to the marine debris load has not been evaluated (Derraik, 2002).
- There is non-lethal physiological risk that may occur due to disturbance.

Summary of how it is dealt with in different countries

Interactions with sensitive species (birds and mammals) is acknowledged as an important potential interactions and risk is considered during licencing by most countries. A full assessment of the likely interactions with mammals and bird species is required for licencing in all countries assessed.

Within the EU the primary legislative driver is the Natura 2000 regulations which is transposed into national regulations. This directive stipulates that all licencing authorities during deliberations must consider the likely impact of the activity on conservation features.

In Canada and China, aquaculture licencing legislation considers risks to marine mammals and birds.

In the USA, a range of national legislations, including the Endangered Species Act (ESA), apply and require that federal permitting agencies consult with NMFS and USFWS if threatened or endangered species or their critical habitat may be affected by proposed aquaculture activities.

Monitoring practices

In certain areas, empirical studies have been used to inform management actions in marine protected areas, for example where a 1.5 km buffer is set around harbour seal haul-out sites in the Dutch Wadden Sea to exclude recreational disturbance (Brasseur and Fedak, 2003). However, there is no broad-scale or systematic monitoring of sensitive species as it relates to shellfish aquaculture interactions. Academic research and targeted small spatial scale monitoring informs policy and management actions.

Emerging issues and prioritized research

- Measures of population-level effects in conservation species birds
- Measurement of habitat requirements (i.e., habitat quality) and subsequent feeding requirements for bird species.
- Confinement of space increases conflict and potential competition for resources and space in species.
- Full understanding of the risks aquaculture gear poses to marine mammals and birds, vis-a-vis entanglement risk.
- Full understanding of the risks aquaculture gear poses to marine mammals migratory and feeding behaviour.
- Important information as it relates to large charismatic species and their feeding and migration patterns.

4.5.2 Effects on sensitive habitat/spawning areas

Concise description of cause

Shellfish cultures can affect sensitive habitats or spawning areas in several ways. The farm animals themselves may compete for space with other organisms from infauna and epifauna to fish (feeding and spawning areas), birds and mammals. Bivalve cultures can cause shading of algae and seagrass through increased turbidity or light limitation by the off-bottom farming structures. Husbandry and harvest activities cause disturbances of sediment through dredging, raking and general maintenance. Off-bottom culture causes increased deposition of both particulate waste and shell fall-offs that has the potential of disturbing habitats located nearby the farm. All these causes are well described in the scientific literature (reviewed by e.g. Kaiser *et al.*, 1998; Keeley *et al.*, 2009; McKindsey *et al.*, 2011). However, focus in these studies are environmental effects in general and very few studies have considered sensitive habitats specifically. Effects on fish is mainly focused on attraction to bivalve culture and farm structures for feeding or hiding, but a couple of studies have considered the possibility that bivalve cultures causes changes in fish recruitment through consumption of eggs and larvae (Broekhuizen *et al.*, 2002; Gibbs, 2004).

Concise description of effects

Since effects of bivalve aquaculture on sensitive habitats or spawning areas has been given little attention, information about this issue is quite limited. Most studies have focused on the interactions between bivalve culture and eelgrass beds but there is no clear consensus on the overall trends and mechanisms. Ferriss *et al.* (2019) conducted a meta-analysis on the effects of both on-bottom and off-bottom shellfish culture on eelgrass, covering a range of topics such as light limitation (shading), increased sedimentation, space competition, and physical disturbance by husbandry and harvesting. The results of the analysis showed that both on-bottom and off-bottom culture has some negative effects on eelgrass, with off-bottom culture having the greatest impact, including reduced eelgrass density, percent cover and reproduction (e.g. Skinner *et al.*, 2013). In contrast, on-bottom culture had, in addition to negative effects on density and biomass, positive effects on eelgrass growth and reproduction. Ferriss *et al.* (2019) point out that bivalve aquaculture and eelgrass has coexisted for more than a century and that shellfish farms hardly preclude eelgrass as long if farmers follow best management practices aimed at reducing impacts from the activity.

A study on maërl beds in Galicia showed that the increased deposition of detritus and fine sediment from suspended mussel aquaculture caused a reduction in cover, degradation, and disappearance of some maërl beds (Peña and Bárbara, 2008b; Peña, 2010) . As for eelgrass, not all maërl beds are negatively impacted by shellfish aquaculture (Peña and Bárbara, 2008a) . Of the 60 maërl beds included in the Peña and Bárbara (2008a) study on long-term changes, 19 of the beds were partially or totally degraded. Of these, 12 were located in the vicinity of suspended mussel farms. In general, a significant decline of live maerl and diversity of the associated flora was observed with an increase of fine sediments from the mussel farms (Peña, 2010). The negative impact of increased sedimentation from finfish aquaculture on maërl beds has been well studied (Barberá *et al.*, 2003; Hall-Spencer *et al.*, 2006) and supports the idea that effects from bivalve farming could be similar.

Summary of how it is dealt with in different countries

In general, there is a knowledge gap on how shellfish farming affects sensitive habitats and what the cumulative effects may be. In USA and Canada, significant research has been conducted regarding impacts of shellfish aquaculture on eelgrass. Norway emphasizes the need for comprehensive and modern spatial planning for shellfish aquaculture.

In addition to the more general regulations for aquaculture activities, a range of water regulation directives, habitat directives, and bird and wildlife directives are part of the regulations. The UK (Scotland) also targets the effects of shellfish culture on sensitive habitats when assessing applications by identifying potential risks to sensitive habitats or wildlife. In China, the State protects aquatic species and their living environment through the establishment of aquatic species protection zones in the main areas where aquatic species of high economic and natural heritage value grow and propagate but do not identify specific vulnerable habitats or spawning areas.

Monitoring practices

Monitoring practices vary greatly between countries. Most countries do not have specific monitoring programs for shellfish aquaculture. Rather, monitoring is undertaken if the shellfish farm is thought to have an effect on sensitive habitats or wildlife in the area. In Ireland, EU-regulations requires conservation status reports every 6 years.

Emerging issues and prioritized research

There is very limited knowledge of the effects of shellfish aquaculture on sensitive habitats and spawning areas generally. One explanation could be that on-bottom and many off-bottom (trestle and bouchot culture) shellfish farms are located in intertidal areas where fauna and flora communities are highly adaptable and less sensitive to impacts caused by the farming activities. In general, there seems to be few or no negative impacts on sensitive habitats or species as long as bivalve culture is restrained to within the carrying capacity of the area.

Bivalve aquaculture in suspended systems is located in areas with deeper water and with a high degree of water exchange to ensure high growth rates and good water conditions for the farmed animals. Areas that have strong currents tend to coincide with ecologically significant or sensitive habitats. A priority should be to increase knowledge of how biodeposits from suspended culture impact both shallow and deep-water communities in close proximity to farm areas.

The need for better tools for the localization of aquaculture farms is crucial. Careful site selection based on habitat mapping (visual mapping and models) can reduce or avoid siting shellfish farms in areas with sensitive habitats and in critical fish spawning grounds and nursery areas. Current models can also be used to simulate dispersal patterns for particulate waste and shell fall-off.

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Annex 2: Resolutions

2018/MA2/ASG02 A **Working Group on Environmental Interactions of Aquaculture (WGEIA)**, chaired by Terje Svåsand, Norway, will be established and will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2018	10–14 December	ICES HQ, Copenhagen, Denmark	Interim report by 1 March	
Year 2019	3–5 September	Stirling, Scotland	Interim report by 30 November	
Year 2020	5-7 May	By correspondence	Final report by 16 June	

ToR descriptors

ToR	Description	Background	[Science Plan codes]	Duration	Expected Deliverables
a	Review of laws and regulatory standards for monitoring and managing environmental impacts of marine aquaculture, and the corresponding thresholds values established by contributing ICES countries with the aim of improving current management options.	Understanding environmental impacts of aquaculture and how they meet, or do not meet legal environmental mandates is limiting further sustainable growth. First, an understanding of the legal environmental drivers which impact marine aquaculture and how they differ among ICES countries is needed. Consistent and transparent science-based management tools to ensure compliance with environmental laws and to build public confidence in the aquaculture industry are needed. Tools based on models, indicators, threshold values and/or monitoring programmes are needed for impacts requiring management in the majority of ICES countries. Examples may include: • Spread of pathogens, incl. pest management • Escapes and genetic interactions • Nutrients and organic loads • Habitat and biodiversity interactions • Animal welfare What use do ICES countries currently make of these management tools and where is improvement possible?	5.6, 7.4	years 1 & 2	Outputs of benchmarking review presented in 2018 & 2019 interim reports.
b	Recommendations for prioritized research to elucidate knowledge	There is a need to move beyond the letter of environmental laws to address the spirit of environmental responsibility.	2.1, 5.6	1&2 year	A prioritized list of current paradigms related to

	gaps in aquaculture-environment interactions needed for effective industry regulation.	The number of studies and reviews in the fields of aquaculture and environment interactions have been increasing during the last 10-20 years, but still there are many knowledge gaps. In addition, there is need to synthesize what is known in some areas into working paradigms and list key environmental interactions in a matrix of species type by production system. To develop the field further, we need continued focus on international cooperation, within the priority thematic areas.			aquaculture/environment interactions for all types of marine aquaculture and research to elucidate knowledge gaps. The report will include suggestions for project proposals and/or ToR for new EGs. Outputs will form part of the interim report in 2019 and final report in 2020
c	Recommendations for risk and benefit assessment methods and models to assess trade-offs associated with aquaculture scenarios	Methods for risk and benefit assessments are not very well developed for marine ecosystems and aquaculture. Building on results from ToR b, WGEIA aims to review and recommend methods and models for assessments including environmental impacts of aquaculture production.	2.1, 5.6, 5.8	year 2&3	Final report in 2020 and an ICES viewpoint and/or publication covering ToR a, b and c with highlighted examples.
d	International cooperation	WGEIA aims to encourage development of at least one international project according to the prioritized research areas in ToR b or c	NA	year 3	Report status at ASC 2020/final report 2020

Summary of the Work Plan

Year 1	Two of reference a (Benchmarking legal standards and monitoring) and b (prioritized terms research) will be initiated in the starting year
Year 2	Terms of reference a) and b) will be further developed and reported. and reference c (Assessment methods and models) will be initiated.
Year 3	Terms of reference c and d (International cooperation) will be reported. Synthesis publication will be produced.

Supporting information

Priority	The current activities of this Group will continue to lead ICES into issues related to aquaculture including elucidating the legal structure under which the environmental interactions of aquaculture are managed in different ICES countries. Scientific work on ecosystem interactions will lay the scientific foundation for further sustainable aquaculture growth to meet or surpass legal requirements. Consequently, these activities are considered to have a high priority.
Resource requirements	Hosting of the first meeting in Copenhagen.
Participants	The Group will be established of 15-25 experts of aquaculture - environment interactions, regulators, legal experts and others
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	This project sets the stage for future advice products from ICES as governments need to manage aquaculture development based upon the requirements of various environmental laws and regulations. Viewpoint documents will provide an example of the types of advice products ICES can produce for aquaculture.
Linkages to other committees or groups	There is a very close working relationship with all the groups of the Aquaculture Steering Group. We will seek to form links with the Working Group on Socio-

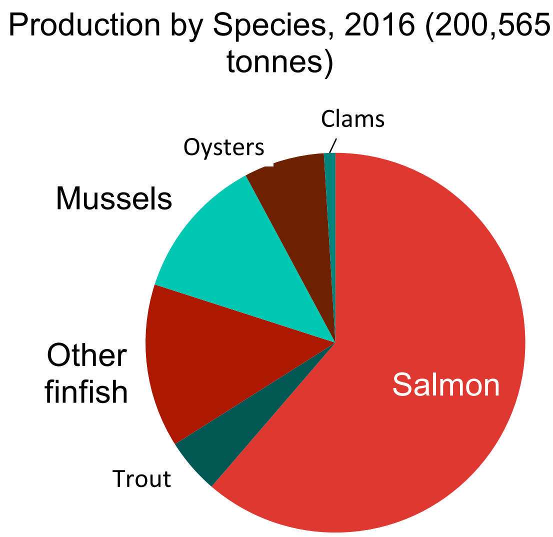
	Economic Dimensions of Aquaculture (WGSEDA) Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM), Working Group on Scenario Planning on Aquaculture (WGSPAQ), and Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA). It is also very relevant to the Working Groups, WGHABD, WGITMO, WG Benthic Ecology
Linkages to other organizations	OSPAR, NASCO, EAFP, EFARO, EATiP, FAO, EU (EUMAP regulation), NOAA, DFO.

Annex 3: National aquaculture overviews

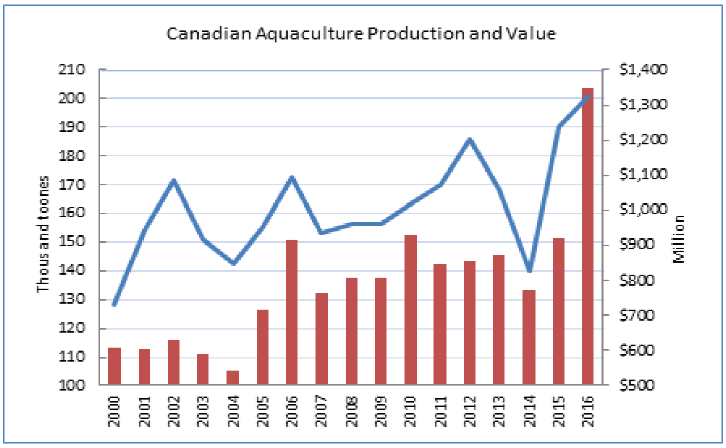
Canada

Production, Growth and Future Prospects

Aquaculture occurs in all provinces and Yukon at varying economic levels. The value of aquaculture production was estimated at $1.35 billion in 2016 and production reached a record high of 200,565 tonnes. In the same year, the aquaculture industry directly employed 3,340 people, mainly in rural, coastal areas and including many Indigenous communities. There continues to be a significant demand at home and abroad for high quality seafood products and the Canadian aquaculture sector has been identified as an economic growth opportunity.



While Atlantic salmon represents a significant portion of the species cultivated in Canada, there are 45 different species of finfish, shellfish and marine algae commercially cultivated in Canada. Mussels and oysters make up nearly 20% of aquaculture production and trout and other finfish account for another 19% of production. The diverse species cultivated in Canada supports a vibrant and growing sector.



Sustainable aquaculture development continues to be a priority for FPT governments. Economic development plans of many provinces and territories identify aquaculture as an opportunity for growth. Governments generally agree there is an increased need for efficient and coordinated regulatory frameworks to address environmental protection while encouraging the investments required for sustainable growth.

Underpinning the sustainable practices and effective regulation of aquaculture in Canada is a history of robust peer-reviewed science advice to inform decision-making, and an active scientific research community addressing key knowledge gaps for regulation and for enhancing the sustainability of the industry. Targeted research relating to fish health, development and evaluation of innovative solutions to industry challenges, such as sea lice, characterizing and predicting genetic interactions, benthic impacts, and shellfish carrying capacity are some of the areas where federal scientists, academics, and industry partners are actively conducting research.

Risk assessments to evaluate the risk from specific aquaculture stressors on identified wild populations are advancing our understanding of the important linkages between aquaculture activities and the potential consequences at a broader level. This synthesis and integration of research results across various fields, such as oceanography, fish health, biosecurity, and fish biology and ecology is providing scientific peer-reviewed advice to aquaculture policy and regulators in Canada on key priorities, thus providing a scientific basis for management or regulatory changes.

Legislative and Regulatory Overview

The aquaculture regulatory system in Canada is complex, with three distinct types of regulatory approaches:

1. DFO is the principal regulator in British Columbia (as of 2009) under the federal Pacific Aquaculture Regulations;
2. Prince Edward Island and Government of Canada share responsibility for regulating and licencing aquaculture; and,
3. Elsewhere, the provinces lead, having responsibility for land tenure management and licensing with provincial statutes and regulations in place.

Federal legislative authority for regulating the aquaculture industry is found in a number of different Acts administered by different federal department and agencies.

- *Canadian Environmental Assessment Act, 2012*
- *Canadian Environmental Protection Act, 1999*
    - *New Substances Notification Regulations (Organisms)*
- *Feeds Act*
- *Feeds Regulations*
- *Fisheries Act*
    - *Aquaculture Activities Regulations*
    - *Atlantic Fisheries Regulations*
    - *Fishery (General) Regulations*
    - *Management of Contaminated Fishery Regulations*
    - *Maritime Provinces Fishery Regulations*
    - *Marine Mammal Regulations*
    - *Pacific Aquaculture Regulations*
- *Food and Drugs Act*
    - *Food and Drug Regulations*
- *Health of Animals Act*
    - *Health of Animals Regulations*
    - *Reportable Diseases Regulations*
- *National Code on Introductions and Transfers of Aquatic Organisms*
- *Oceans Act*
- *Pest Control Products Act*
- *Species at Risk Act*

Provinces have day-to-day operational responsibilities, which include:

- Issuing leases (except for Prince Edward Island);
- Issuing licences (except for British Columbia and Prince Edward Island);
- Regulating limits on benthic material accumulation;

- Fish health;
- Sea lice;
- Containment and escapes;
- Pesticide use and sale;
- Development of appropriate regulatory and legislative instruments; and,
- Industry promotion.

More information on the federal, provincial and territorial acts and regulations can be found at: https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/regs-eng.htm.

Planning and Management of Aquaculture

The Government of Canada supports the development of aquaculture that is environmentally responsible, economically sound, and socially progressive. DFO works with provinces and other government departments to ensure that the aquaculture sector is appropriately regulated including environmental protection and strong compliance monitoring and enforcement.

Many provinces have developed strategic plans and growth goals for aquaculture. Federally, Fisheries and Oceans Canada is responsible for the conservation and protection of fish, which for development projects in or near coastal waters, follows the principles that to protect fish and fish habitat, including aquatic species at risk, efforts should be made to avoid causing serious harm, to mitigate any harm that may be caused and to offset any residual harm.

For aquaculture, proper siting of the facility is the primary and most important tool for avoiding causing serious harm and then to mitigate the residual predicted risks to commercial, recreational and Aboriginal fisheries resulting from habitat degradation or loss, alterations to fish passage and flow, or aquatic invasive species.

To date siting decisions are mostly made on a farm-to-farm basis, although there is specific consideration of minimum distances between farm sites, distances from proposed sites and salmon-bearing streams, and maximum production levels permitted for shellfish in certain bays. Increasingly, there is an interest provincially and federally to consider area-based strategies. Recently, some provinces have developed legislation or initiatives that put stronger emphasis on area-based strategic tools. For example, the new legislative framework for Nova Scotia considers the designation of aquaculture development areas. In addition, the federal government has recently announced a renewed approach to aquaculture management that includes a focus on area-based approach to aquaculture development. This approach seeks to ensure that environmental, social and economic factors are taken into consideration when identifying potential areas for aquaculture development, including considerations relating to migration pathways for wild salmon.

Prior to the establishment of a new aquaculture facility or significant changes to an existing aquaculture facility, the Provincial, Territorial and Federal governments require the aquaculture industry to submit information for assessment as part of the leasing and licensing process.

Regardless of where the new or expanded facility is located, the range of proposed activities, the anticipated stressors and environmental and ecosystem effects are considered. In Canada, the likely impacts from a development proposal on conservation and protection of fish and fish habitat are assessed using a Pathways of Effects model.

Pathways of Effects models are used to describe development proposals by the: activities that are involved, the type of cause-effect relationships that are known to exist; and the mechanisms by which stressors ultimately lead to effects in the aquatic environment.

Each cause-and-effect relationship is represented as a line, known as a pathway, connecting the activity to a potential stressor, and a stressor to some ultimate effect on fish and fish habitat. Each pathway represents an area where mitigation measures can be applied to reduce or eliminate a potential effect. When mitigation measures cannot be applied, or cannot fully address a stressor, the remaining effect is referred to as a residual effect.

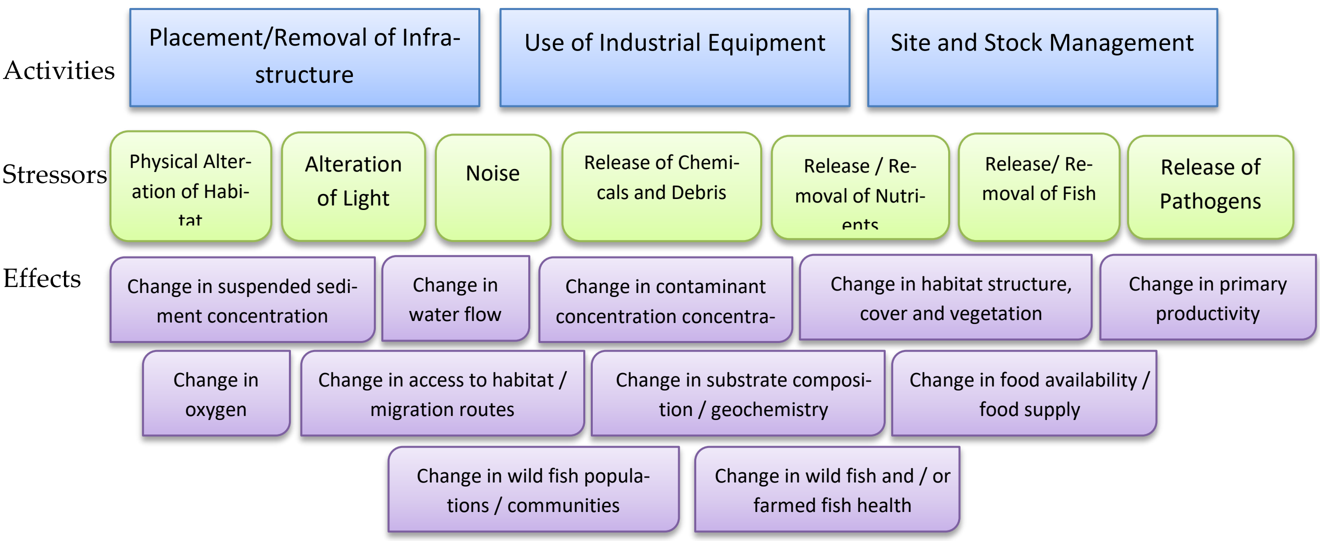
The Aquaculture Pathways of Effects model was developed collaboratively with Provincial and Territorial regulators. A scientific workshop to peer review the scientific basis for the linkages between the major stressor categories associated with aquaculture activities, the resulting stressors that can result, and the potential effects of these stressors on different ecosystem and environmental components was completed (see DFO, 2009). As additional data from monitoring around aquaculture sites and new scientific research results becomes available, the characterization of the duration, scale and intensity of the stressor-effects relationships will need to be reviewed and updated to reflect this new information.

To protect fish and fish habitat, including aquatic species at risk, efforts should be made to avoid causing serious harm, to mitigate any harm that may be caused and to offset any residual harm.

Pathway of Effects models can be used by both regulators and proponents to:

- Review the potential effects of individual development proposals;
- Identify appropriate mitigation measures;
- Develop guidelines and best management practices; and
- Assess the effects of alternative design options.

Pathways of Effects for Finfish and Shellfish Aquaculture



The assessments and risk management strategies applied prior to the establishment of an aquaculture facility are critical to avoiding impacts on fish and fish habitat. Through proper siting, many stressor-effects can be avoided. Those that remain may then be mitigated through operational or site-specific requirements, and the acceptable impacts may then be evaluated by comparing operational performance monitoring results to regulatory thresholds.

All of the stressor-effects relationships should be evaluated at the pre-site stage.

Only the primary regulations that are used in assessing each stressor are listed.

Physical alterations to the habitat occurs during placing or removing of the physical infrastructure (e.g., net pens, longlines, rafts, anchors and moorings, shellfish beach culture structures), as well as during the use of husbandry equipment (e.g., underwater lights to increase growth in marine finfish).

The extent and impact of the predicted physical alterations to habitat are considered primarily during the pre-operational stage (e.g., site application), which includes an evaluation of the type of benthic habitat in the area being proposed for aquaculture.

This is regulated federally under the *Fisheries (General) Regulations*, and the *Aquaculture Activities Regulations*. Provincial regulations may also apply. While there are no thresholds applied across applications, the type of habitat, the use of the habitat by wild fish species, the extent coverage or predicted alternation in habitat at the larger scale, and other interactions are considered. Management measures available include modifications to the proposed structure location or orientation, scale limitations within the larger area.

Release of chemicals and debris occurs primarily with activities associated with site and stock management, and the use of operational equipment where chemicals and debris may be released. Examples include the use of pesticides, drugs and antifouling agents, and the use of materials in construction (e.g., steel, wood, floatation) and operations (e.g., feed bags, ropes), which can be lost from sites as debris.

The effect of the use of pesticides, drugs and antifoulants on the receiving environment, including on non-target organisms, is assessed by Health Canada. The use of pesticides and drugs to treat sea lice, viruses and bacteria on finfish is overseen by a veterinarian. The deposit of pesticides, drugs, disinfectants, and other chemicals is authorized under the *Aquaculture Activities Regulations,* after all other measures have been considered for use.

To further predict the potential impact of these chemicals at the siting and operational stages of an aquaculture facility, Fisheries and Oceans Canada and its regulatory partners (Health Canada and Environment and Climate Change Canada) are working collaboratively on the development of an integrated assessment model, and post-deposit monitoring program.

Release of organic and related matter occurs as a result of stock management activities (e.g., the feeding and cultivation of fish, removal or natural sloughing of biofouling organisms from physical infrastructure) that have an organic or related component (e.g., nutrients).

The predicted extent of organic deposition on the surrounding seabed is assessed at the pre-operational stage and assessed during the operation of the site through environmental performance (compliance) monitoring for marine finfish sites.

Operational monitoring is to be undertaken at least once the production cycle at sea or every 24 months for farms with finfish continuosly on site. Monitoring occurs either within 30 days of peak feeding or peak biomass, or between July 1 and October 31 close to peak feeding. Different metrics are used for seabed depending on whether or not a benthic substrate can be sampled. Sampling is not required within areas of the tenure or 1 g C/m2/day depositional contour where depths exceed 300 m. Details on the monitoring design can be found at: http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/doc/AAR-Monitoring-Standard-2018-eng.pdf. A marine finfish facility must not restock if the mean concentration of free sulphides measured in the compliance sampling exceeds the regulatory threshold (mean concentration of free sullied exceeding 3000 uM in marine finfish sites in tidal waters in or adjacent to Quebec, Nova Scotia, New Brunswick, Prince Edward Island, or Newfoundland and Labrador; mean concentration of free sulphide exceeding 1300 uM and 700 uM at 30 m and 125 m respectively, from the structure).

Federally, both the pre-site assessment and the performance monitoring is regulated federally under the *Fisheries (General) Regulations,* and the *Aquaculture Activities Regulations.* Additional provincial requirements outlined either in provincial legislation or regulations, or through conditions of licence, can be defined.

Removal of nutrients and organic matter occurs as a result of stock management activities where some cultured species (e.g., bivalves) remove particulate matter, nutrients and oxygen from the water column.

The predicted extent of the removal of nutrients on wild populations is assessed at the pre-operational stage, based on some form of carrying capacity model. Federally, this is regulated under the *Fisheries (General) Regulations.*

Release or removal of fish occurs primarily as a result of stock management activities.

The removal of fish is considered and managed under DFO's bycatch policy (DFO's Policy on Managing Bycatch under the Sustainable Fisheries Framework http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/bycatch-policy-prise-access-eng.pdf). This occurs when some individual wild fish may be temporarily or permanently removed from waters along with cultured fish (e.g., during grading or at harvest), or as part of biofouling or predator control.

The addition of fish to the environment occurs either as a result of intentional stocking of cultured fish into aquatic environments for cultivation (e.g., salmon enhancement), or as a result of unintentional release of fish (e.g., escapes).

The impact on wild populations from the unintentional release of cultured organisms is currently considered at the pre-operational stage, and is linked to fiduciary responsibilities associated with the *Species at Risk Act*. It is also considered by the Introductions and Transfers Committee in the assessment of requests for non-routine introductions or transfers, under the s.56c of the *Fishery (General) Regulations.*

Reporting of escaped fish is managed through the conditions of licence that are set by the provincial governments or by Fisheries and Oceans under the *Pacific Aquaculture Regulations* in British Columbia. Recapturing escaped fish may be licensed through a finding licence through Fisheries and Oceans Canada.

Release of pathogens and pests occurs associated with site and stock management. The increase in biomass of fish within an aquaculture site can influence the presence or abundance of fish pathogens (e.g., bacteria, viruses) and pests (e.g., sea lice and tunicates).

The introduction of pathogens or pests is evaluated at the operational stage, primarily by the Introductions and Transfers Committees (ITC), under s.56b of the *Fishery (General) Regulations*, and is assessed by the Canadian Food Inspection Agency.

Conditions of licence (either provincial/territorial/federal) outline mitigation measures for the surveillance and management of the abundance of pathogens or pests.

Notifiable diseases are regulated by the Canadian Food Inspection Agency under the *Health of Animals Act*.

Research to support management decisions as it relates to the transfer of shellfish from MSX-positive zones continues to be a research priority, as is addressing key knowledge gaps related to the characterization of pathogens, the host-pathogen response, and the key environmental parameters that can influence the host-pathogen response. The risk of the transfer of pathogens from Atlantic salmon farms to the population and abundance of Fraser River Sockeye salmon is currently being assessed. See: http://www.dfo-mpo.gc.ca/aquaculture/sci-res/aserai-eng.htm.

Knowledge gaps

Research and formal science advice following the polices and coordinated by Fisheries and Oceans Canada's Canadian Science Advisory Secretariat, will continue to support improvements in the assessments of new site applications, area-based planning initiatives and approaches, refining operational monitoring and assessment tools, and introductions and transfers decisions. Additionally, regulatory environmental monitoring results and regulatory reporting results provide feedback and information on decisions which supports adaptive management.

Fisheries and Oceans Canada's priorities for research fall broadly into the categories of: (1) environmental management or performance; (2) fish health; (3) genetic interactions; (4) interactions with other species; and (5) ecosystem and carrying capacity modelling.

Scientific and technical advice to support policy and regulatory improvements in Canada are currently underway in the following areas:

- Development of advice on options for the development of a post-deposit monitoring program for drugs and pesticides used in aquaculture.
- Development of National standards on (1) containment standards for marine finfish cages, and (2) monitoring and metrics for assessing organic loading.
- Technology study on closed containment
- Improving the communication of scientific results/social acceptability
- Recent announcement of a commitment between the federal, provincial and territorial fisheries and aquaculture ministers for the development of a new Aquaculture Acct to streamline management of aquaculture (December 5, 2018).
- Policy development to better define (1) a framework for aquaculture risk management, and (2) the application of the Precautionary Approach
- Pilot project of an Area-based management approach.

References:

DFO. 2009. Pathways of Effects for Finfish and Shellfish Aquaculture. Science Advisory Report 2009/071. http://www.dfo-mpo.gc.ca/csas-sccs/publications/sar-as/2009/2009_071-eng.htm

Denmark

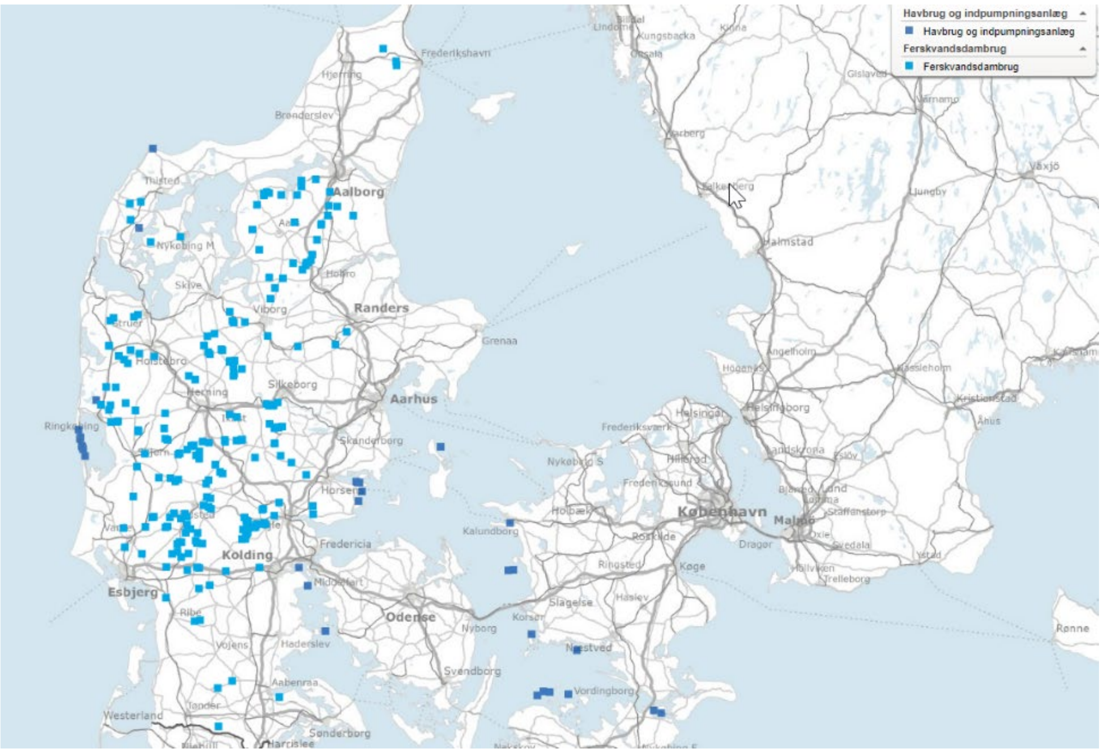


Figure 1. Placement of sea cage fish farms and farms with inlet of marine waters (dark blue) and freshwater fish farms (light blue)[9]

Production statistics and trends

In Denmark the term aquaculture covers any type of farming of fish, other aquatic species and plants in marine or freshwater.

The main species farmed in Denmark are rainbow trout, which is farmed in both freshwater (pond, raceways, RAS[10]) and sea cage in marine water. Other species so as eel, pike perch, salmon, yellow tail (king fish), sturgeon are farmed in RAS-systems and mussel farming, mainly blue mussel, is farmed in the water column in longlines or smartfarm-systems. Seaweed farming in Denmark is currently only on experimental level with many experiments going on especially on sugar kelp.

The placement of fishfarms is shown in figure 1, and the aquaculture production is given in table 1.

Table 1. Production in aquaculture in Denmark (tons a year)[11]**.**

	2013	2014	2015	2016	2017	2018
Total production	42.761	43.965	46.890	45.619	48.300	47.461

[9] Ministry of environment GIS http://miljoegis.mim.dk/ 21.12.2018

[10] RAS: fully recirculated land-based farms, normally indoor.

[11] National statistic Denmark: https://www.dst.dk/da/Statistik/emner/erhvervslivets-sektorer/fiskeri-og-akvakultur 19.2.2020

Mussel and Oyster	574	1.810	1.809	2.251	2.814	4.516
Sea cage	10.506	11.115	11.724	10.117	11.427	10.661
Freshwater farms - traditional	15.424	15.757	15.118	14.351	14.934	13.205
Freshwater farms - model 1 and 3	12.144	11.249	13.209	12.743	13.062	13.323
Other farms	4.113	4.034	5.029	6.158	6.063	5.755

Trends and further development

There are 19 sea cage farms in Denmark with a production around 10.000 – 12.000 tons fish a year, and there has been no new permissions or production increases in around 20 years, all though there has been several applications, and several experiment with IMTA (nitrogen and phosphor uptake by mussel production) and offshore farming.

The Danish administration of the EU legislation especially the water frame directive[12] and the habitat directive[13] and also the HELCOM convention[14] is the greatest barrier to growth in sea cage farming, and today it is even unknown if it is possibly for an existing sea cage farm to get a renewal of an existing environment permission.

The consequence of the Danish administration is that there have been no growths in sea cage farming, and the main barrier is ”environmental space” (discharge of nitrogen and phosphor), location (special planning) and the EU habitat directive.

Dansk Aquaculture, the producer’s organization, is running a court case against the Danish state concerning the Danish administration of especially the habitat directive for an existing sea cage farm.

Probably other ICES countries are facing the same problems and barriers for growths, and hopefully ICES can come up with some guideline or tools to solve this?

Relevant International and EU legislation

Denmark is an EU member and both Denmark and EU has ratified the Helsinki Convention.

HELCOM convention[15]: Legal instrument to reach good ecological water quality the Baltic Sea. All the country around the Baltic sea included Russia and EU has ratified the convention.

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[12] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

[13] Habitat directive. Eu Directive 92/43/EEC of 21 May 1992

[14] Helsinki-Convention (1992): Convention on protection on the marine environment in the Baltic Sea Area.

[15] Helsinki-Convention (1992): Convention on protection on the marine environment in the Baltic Sea Area.

Water frame directive:

The overarching legal framework for aquaculture farming is the water frame directive which has been implemented in Danish legislation as consolidated act no. 119 issued January 26th 2017[16].

The purpose of the water framework directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. The law does not introduce legal tools per se for enforcement, but it specifies the overall environmental objectives that fish farms have to operate within and it furthermore determines how the objectives shall be met. This is done via specific and legally binding action plans at both sector and company level (programme of measures).

The law introduces further restrictions on freshwater farming. The most critical restrictions are related to discharge of nutrients (nitrogen and phosphorus) and organic matter and restrictions on water intake by quantity (cubic meters), source (surface and groundwater) and river continuity in terms of stems and water intake.

All the existing marine farms are covered by the water framework directive. The most critical issue for marine sea cage farming in Denmark in relation to the water framework directive is discharge of nitrogen. There are no efforts to reduce discharge of nitrogen from sea cage farming in the Water-area-managements-plans.

Habitat directive[17] (and Bird directive[18]):

Another substantially overarching legal framework for aquaculture farming is the habitat directive which has also been implemented in Danish legislation as consolidated act no. 119 issued January 26th 2017[19].

Especially article 6.3 in the habitat directive is important for aquaculture. For new farms, for any significant change in an existing farm, for renewing water intake permissions, location permission and in some cases even for renewing an existing permission the fish farmer must prove that there is no effect on the integrity of the habitat areas after article 6.3[20].

Other important directive due to aquaculture: EIA Directive[21], Marine strategy Framework directive[22],
Maritime Spatial Planning Directive [23]

Environmental regulation on aquaculture in Denmark

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[16] lov om miljømål m.v. for internationale naturbeskyttelsesområder (Miljømålsloven) No. 119, 26.01.2017

[17] Habitat directive. Eu Directive 92/43/EEC of 21 May 1992

[18] Bird Directive. EU directive 2009/147/EEC of 30 November 2009 on the conservation of wild birds

[19] lov om miljømål m.v. for internationale naturbeskyttelsesområder (Miljømålsloven)

[20] Habitat Directive Article 6.3: *"Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. In the light of the conclusions of the assessment of the implications for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public."*

[21] EIA DIRECTIVE 2014/52/EU of 16.4.2014 on the assessment of the effects of certain public and private projects on the environment

[22] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

[23] Maritime Spatial Planning Directive 2014/89/EU

There is no specific law on aquaculture in Denmark hence the legal framework is built upon other relevant legal acts. The following covers only environmental legislation for the most important aquaculture activities. The environmental legislation on aquaculture exists on two levels. There are general legal acts that basically all types of economic activity must comply with and there are specific legal acts for the various forms of aquaculture i.e. freshwater farming, marine farming and mussel farming.

Danish version of all mentioned legal acts can be found at www.retsinfo.dk by using a simple search engine (act number and date of issue).

Aquaculture production also needs permissions according to veterinary rules, which will not be further described in this text.

BAT (Best Available Technology)

There is no binding requirement either under EU-legislation or Helsinki Convention on the use of BAT (Best Available Technology) or BEP (Best Environment Practice) in Aquaculture.

Freshwater fish farms or marine cage farms are not subject to the EU legal principle of BAT in the IE Directive[24], and the Helsinki Convention only requires that the participating country to promote the use of BAT / BEP[25].

In contrast to this, Denmark has decided to include mandatory requirements for BAT in fish farming in the national legislation. Based on a survey of several Western aquaculture nations, DTU Aqua in 2013[26] estimated that only Denmark has mandatory BAT requirement for regulation of aquaculture.

Marine sea cage farming

Today there are 19 sea cage farms in Denmark with an annual production around 11,500 tons fish. The production circle is seasonal due to risk of floating ice and toxic algae. Fish are put into the cages in April at size 600 – 800 g and are harvested as 3-4 kg fish in October-November.

Table 2. Data on marine sea cage farming in Denmark[27]

Number of sea cage farms in Denmark (2019)	19
New farms in the last 20 years	0
Discharge (max N outlet)	6,5 t – 100 t/N year

[24] IE-direktivet nr. 2010/75/EU of 24. november 2010 Industrial Emissions.

[25] Helsinki-Convention (1992): *Art. 3.3. In order to prevent and eliminate pollution of the Baltic Sea Area the Contracting Parties shall promote the use of Best Environmental Practice and Best Available Technology. If the reduction of inputs, resulting from the use of Best Environmental Practice and Best Available Technology, as described in Annex II, does not lead to environmentally acceptable results, additional measures shall be applied." Annex II. 2: " In order to prevent and eliminate pollution the Contracting Parties shall use Best Environmental Practice for all sources and Best Available Technology for point sources, minimizing or eliminating inputs to water and air from all sources by providing control strategies."*

[26] Notat DTU Aqua, 30. april 2013 "Vurdering af RAS i forhold til havbrugsproduktion" http://danskakvakultur.dk/media/4505/DTU-Aqua_BAT-Notat-maj-2013.pdf.

[27] Water-area-management Plan table 3.10 https://mst.dk/natur-vand/vandmiljoe/vandomraadeplaner/vandomraadeplaner-2015-2021/vandomraadeplaner-2015-2021/

N efficiency:	35 - 40 kg N / t fish produced
Total max outlet from sea cage farms	373 t/year
Total outlet to the marine environment from all land-based sources	62,813 t/year

For being permitted to operate, a marine sea cage farm needs a location permission and an environmental permission.

All permits for marine farms located within one nautical mile are issued by the municipality in which the farm is located whereas permits for marine farms located outside one nautical mile is handled at the state level in the Environmental Ministry.

All permits for marine sea cage farms both location permit, and environmental permits must also be subjected to a public hearing process. Any appeal cases will be handled by the Environmental Board of Appeal.

Location permits
A location permission is granted under Fisheries law no. 764 of 19. June 2017[28] and order no. 1489 of 6. December 2016[29]. The main focus in a location permission is other users and other interests, environment and nature. A habitat assessment is included according to the order concerning habitats No.1240 of 24. October 2018[30]. Normally a location permission is valid for 10 years.

Environmental permits
An environmental permission is granted under the environmental protection law no. 1121[31] issued 03. September 2018, and order no. 1317 from 20. November 2018[32]. This is also covered by the rules on EIA screening, and a habitat assessment which are found in order no. 1240 from 24. October 2018[33]. An environmental permission is a framework approval that entitles a maximum production that is normally regulated in relation to a discharge quota of N and P, and maximum use and outlet threshold of chemicals.

For use of medicines and chemicals marine sea cage farms also must comply with the requirements for discharge of residues of medicines as stipulated under order no. 1625 issued 17th December 2017[34]. To get a permission the sea cage must prove by tree-dimension hydrodynamic-models that the production can comply with the threshold in the water column (short time and longtime).

In Denmark it is only allowed to use cobber as antifouling agent and the following antibiotics: Trimethoprim, Sulfadiazim, Oxolin acid.

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28 Fiskeriloven no. 764, 19.06.2017

29 Havbrugsbekendtgørelsen no. 1489, 6.12.2016
30 Habitatbekendtgørelsen no. 1240, 24.10.2018

31 Miljøbeskyttelsesloven no. 1121, 03.09.2018
32 Godkendelsesbekendtgørelsen no.1317, 20.11.2018
33 Habitatbekendtgørelsen no. 1240, 24.10.2018

34 Bekendtgørelse om fastlæggelse af miljømål for vandløb, søer, overgangsvande, kystvande og grundvand no. 1627, 17.12.2017

Due to low salinity in the inner Danish waters there are no problems with sea lice in Danish sea cage farms. The farms make a regular sea lice monitoring but no treatment is necessary or allowed.

Escapes
There is no risk of genetic impact on wild species in Denmark. The farmed species is rainbow trout, and the rainbow trout cannot breed in Danish streams and there is no genetic interaction with local trout or salmon species.

BAT
Further a mandatory BAT-description is included in the environmental permission, and the sea cage farmers must every year make a written statement for improvement in BAT before production start in April[35].

Monitoring
Monitoring plan in an environment permission consist normally of:
Water column analyses: Salinity, temperature, O_2. Samples are taken on daily or weekly basis.

Sediment analyses: N, P, Redox, Cu, medicine. Samples are taken by independent 3. party companies under the nets, up- and downstream, a reference station etc. There must not be any significant increase under the fish farm.

Film under the net cage in August or September. There must be no sludge under the nets and the condition at the seabed must be good.

An environment permission does not expire but will generally be renewed every 10 years. There will be an 8-year legal protection, for a permission due to investment.

Freshwater farming

For being permitted to operate, a freshwater fish farm needs an environmental permission and a license to water intake. All permits and license are issued by the municipality in which the farm is located and must also be subjected to a public hearing process. Any appeal cases will be handled by the Environmental Board of Appeal.
Environmental permission

Freshwater farms must have an environmental permit granted under the environmental protection law no. 1121[36] issued 03. September 2018. This law sets the overall framework for issuing such permits and covers basically all types of economic activity including fish farming.

Order no. 156737 issued December 7th, 2016 covers specifically freshwater farming. This order sets down several provisions that all freshwater farms must comply with. It includes among other things requirements for the use of best available technology, limits on discharge of nutrients and organic matter, threshold for discharge of medicine and chemicals, requirements for farm construction, handling of sludge, registration obligations, minimum oxygen content in outlet water, maximum allowable water intake etc.

[35] Havbrugsvejledningen (Sea cage guideline) no. 9163, 31.03.2006

[36] Miljøbeskyttelsesloven no. 1121, 03.09.2018
[37] Dambrugsbekendtgørelsen no 1567 7.12.2016

The order covers two forms of regulation. Farms may until 2022 choose to be regulated on their output (nutrients, organic matter etc.) but they can also choose to be regulated on input (amount of allowable feed usage). Farms that choose to be regulated on input are not allowed to increase production, whereas there are no production limits on farms that are regulated on output – provided of course that they comply with output requirements.

The permission is also covered by the rules on EIA screening, and a habitat assessment which is found in order No. 1240 from 24. October 2018[38].

Discharge of residues of medicines is regulated by order no. 1625[39] issued 19.12.2017. The order specifies maximum allowable concentrations of various chemical substance including medicines, formaldehyde, copper etc. in freshwater and marine water. When issuing a permit, the municipality must make sure that it complies with the specified concentrations. Order no. 1567 specifies turnover rates for medicines etc. When applying for a permit the farmer must calculate expected discharge of e.g. medicines based on given turnover rates.

BAT

There is different mandatory BAT–requirement depending on the size of the production for freshwater fishfarming in Denmark and regulation form. E.g. is the maximum outlet for a trout farm on outlet regulation producing more than 230 tons fish a year around 27 kg N and 1,4 kg P per tons trout produced. See also appendix 1.

An environment permission does not expire but will generally be renewed every 10 years. There will be an 8-year legal protection, for a permission due to investment etc.

License to water intake

Freshwater farms also need a license for intake of water. This is regulated under consolidated act no. 118 issued on 22.02 2018[40]. This order only regulates the amount of water and the source of water (surface water or groundwater).

The license to water intake also includes an environmental impact assessment screening, and a habitat assessment which is found in order No. 1240 from 24. October 2018[41].

A water license is normally valid for 10 years, thereafter, has to be renewed.

RAS farming

There are several RAS farms in Denmark both using freshwater or seawater.

Permissions to operate a RAS farm is very much like permissions for a freshwater fish farm. The difference is that there are no special orders which covers RAS farming and there are no specific BAT requirements.

Mussel farming

[38] Habitatbekendtgørelsen no. 1240, 24.10.2018

[39] Bekendtgørelse om fastlæggelse af miljømål no. 1625, 19.12 2017

[40] Vandforsyningsloven, no. 118, 22.02.2018

[41] Habitatbekendtgørelsen no. 1240, 24.10.2018

A distinction is made between two types of breeding of mussels and oysters. Breeding in the water column at longline or smart farm systems, and production where farmed mussels or oysters are laid out in defined areas on the seabed.

Production permission is granted under Fisheries law no. 764 of 19. June 2017[42] and for production in the water Colum after order no 1387 from 3.12.2017[43], and for permission for production at the seabed order no. 764 19.06.2017[44]

A habitat assessment is included according to the order concerning habitats No.1240 of 24. October 2018[45].

Normally a permission is valid for 10 years.

[42] Fiskeriloven no. 764, 19.06 2017

[43] Bekendtgørelse om opdræt af muslinger og østers i vandsøjlen no 1387, 3.12.17

[44] Bekendtgørelse om kulturbankeproduktion af muslinger og østers no. 764, 19.06.2017

[45] Habitatbekendtgørelsen no. 1240, 24.10.2018

Appendix 1. BAT requirement in the freshwater fish farm Order (no. 1567 7.12.16)

Table 1. **Maximum allowed outlet for fish production under size 1 kg fish.**

Productions size	**Nitrogen**	**phosphorous**	**BOD**
	kg/ton fish	**kg/ton fish**	**kg/ton fish**
0 - ‹25 tons	42 + 5,5/25*(25-X)	2,5 + 1,4/25*(25-X)	55 + 24/25*(25-X)
25 - ‹55 tons	35 + 7/30*(55-X)	2,2 + 0,3/30*(55-X)	39 + 16/30*(55-X)
55 - ‹230 tons	27 + 8/175*(230-X)	1,4 + 0,8/175*(230-X)	28 + 11/175*(230-X)
≥230	27 kg/ton fish	1,4 kg/ton fish	14 kg/ton fish

Table 2. **BAT requirements to produce large trout (over 1 kg fish, but not for broodstock)**

Productions size	**Nitrogen**	**phosphorous**	**BOD**
	kg/ton fish	**kg/ton fish**	**kg/ton fish**
0 - ‹25 tons	44	4,2	87
25 - ‹55 tons	39	3,1	71
55 - ‹230 tons	30	2,7	37
≥230	27	1,8	19

Faroe Islands

Introduction

Since the 1980s the Faroese aquaculture industry has almost predominantly farmed Atlantic Salmon. There are currently 3 aquaculture companies which farm Atlantic Salmon (Hiddenfjord, Bakkafrost and Mowi, whilst two other producers have in the last decade been cultivating macroalgae (Ocean Rainforest and Tari – Faroe Seaweed).

Salmon aquaculture has become a substantial contributor to the Faroese Economy, with the export value increasing 800 % from in the years from 2007 to 2019. Around half of Faroese export value is Atlantic Salmon, with an export value of 4 billion DKK in 2019. The aquaculture activity is an important source of employment in local communities with production taking place across the country (see Figure 1 for an overview of licences and land-based facilities)

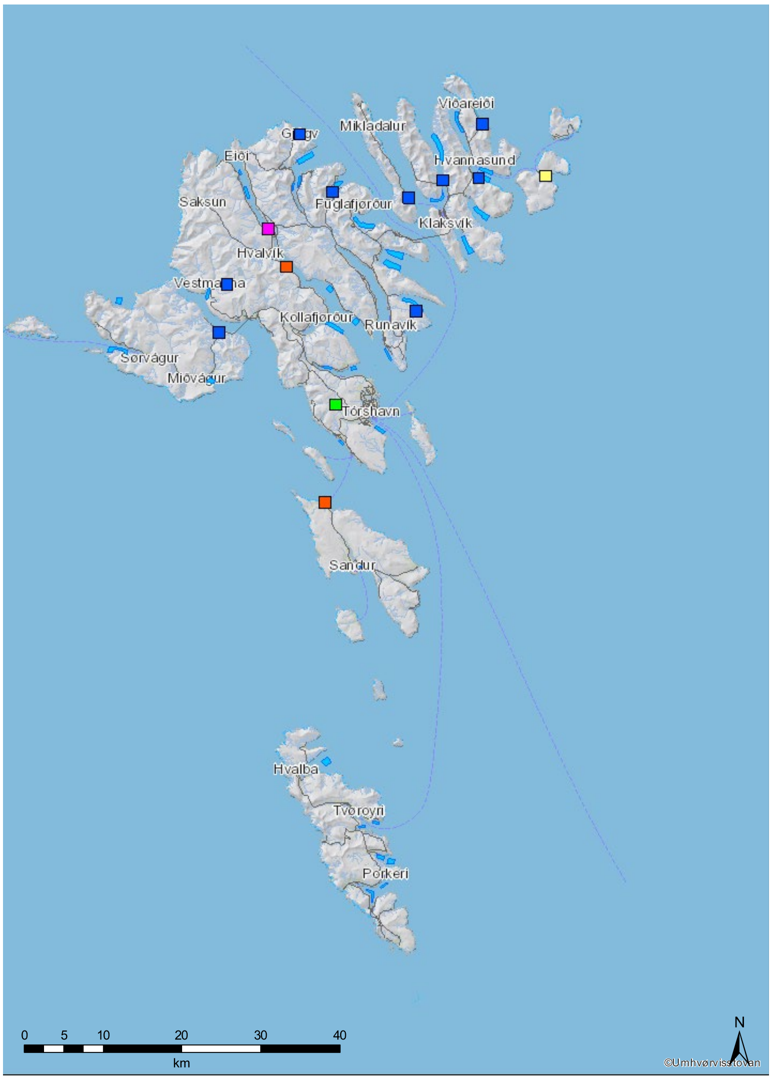

Figure 3. Map of land-based facilities and farming licences across the Faroe Islands (Source: Umhvørvisstovan - kortal.fo).

Production statistics and trends

As demonstrating in Figure 2, both the quantity and value of salmon production has increased by about 800 percent since the mid-2000s, following the crisis with ISA outbreaks. According to

Statistics Faroe Islands, in 2019 the production of salmon was just over 80.000 tonnes in round weight with an export value of about 4 billion. Up to 2010, there was some farming of rainbow trout, with the highest production being 7,985 tonnes in gutted weight in 2003 (Statistics Faroe Islands).

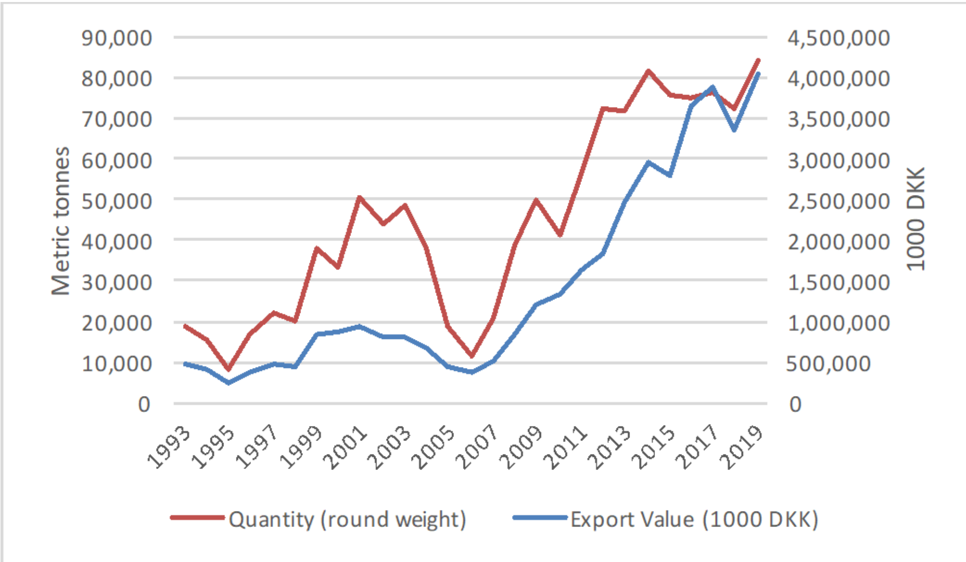

Figure 4. Quantity (Metric tonnes round weight and value (DKK) of Atlantic salmon 1993 - 2019 (source: Statistics Faroe Islands).

Figure 3 illustrates the export value of various fish commodities in the Faroe Islands. The export value of Atlantic salmon has increased both in general, and as a proportion of the total value.

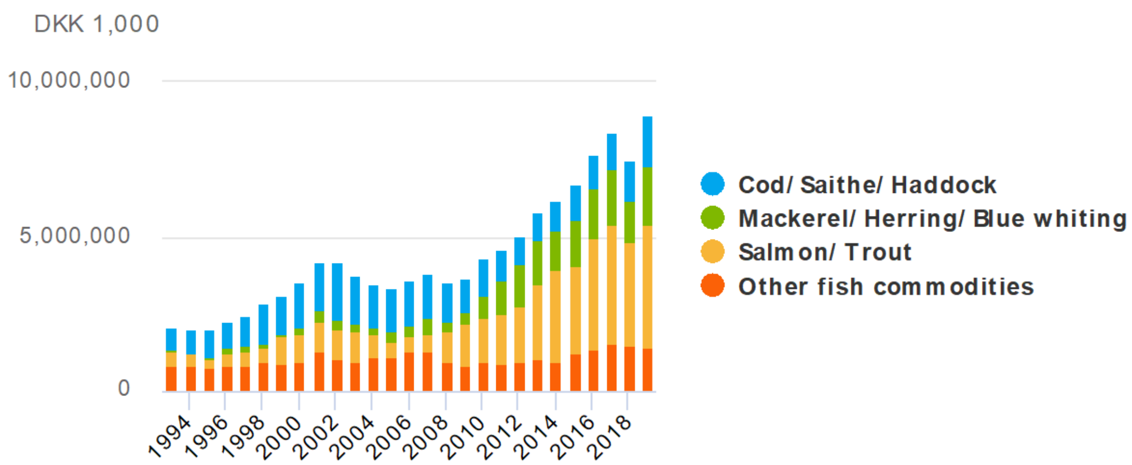

Figure 5. Export value of fish commodities from 1993 - 2019 (Source: Statistics Faroe Islands)

Aquaculture governance

A license is required to be able to farm in the fjords around the Faroese. There are currently 36 active farming licences (Faroese Food and Veterinary Authority 2020), which can also be seen in

Figure 1 above. In terms of management, the ocean around the Faroe Islands has been divided into fjords and farm sites/areas. Up until 2019, only one licence holder was permitted to farm in each fjord.

In 2003, the Faroe Islands implemented a new aquaculture legislation with stringent veterinarian and environmental regulations in particular with the objective to combat problems with diseases and ensure the sustainability of the industry. In 2019, a regulation was introduced to allow for diversification of Faroese aquaculture, by expanding the range of species that can be farmed to include other plants (macro-and microalgae) and other marine species). Up until recently, other species could only be farmed in agreement with the licence holder of the area. Earlier this year, there was a call for applications for permits for macroalgae farming. These applications for macroalgae cultivation licenses are currently in review.

Management tools for development of sustainable aquaculture and regulations

Spread of pathogens

Virtually all farming areas in the Faroe Islands are connected by the clockwise residual current around the Islands, and the same current implies that only a few particles are lost from the system (Kragesteen 2018). Thus, pathogens will readily disperse to the entire fish farming industry once they are established. Accordingly, the legislation is highly focused on preventing spread of disease with single year class at each farming fjord and mandatory fallowing of at least 2 months between production cycles. There are also mandatory surveys of various diseases and detailed regulations on the management of the fish farming sites such as disposal of dead fish and movement of equipment between areas (Regulations on disease prevention, 80 frá 14. Juni 2019).

Sea lice management

Salmon lice are a major obstacle for increased commercial production of Atlantic salmon, as the control of salmon lice at the various fish farms is a prerequisite for increase of biomass according to the legislation. Sea lice are counted biweekly by a third party at all fish farms and the current threshold for adult female salmon lice is 1.5 lice/fish in average for the farm. From June 2020, the threshold will be reduced to one, and in June 2021 it will be reduced further to 0.5 lice/fish.

If the number of lice exceed the threshold and if sealice treatments are conducted the fish farm will get penalty points. The total number of penalty points during the production cycle determines the maximum allowed number of fish during the next production cycle.

(Sea lice regulation, nr 75 frá 28. Juni 2016).

The number of adult female salmon lice and amount of salmon at each farm are publicly available.

VAKSNAR KVENNLÝS	AS-NUMMAR	ALIØKI	ALISTAÐ	LOYVISHAVARI	DAGFESTING FYRI TELJING
0.37	AS-24	A-63	Árnafjørður	Bakkafrost Farming P/F	23-04-2020
0.20	AS-07	A-11	Hvannasund suður	Bakkafrost Farming P/F	23-04-2020
0.53	AS-03	A-27	Miðvágur	Luna P/F	23-04-2020
0.40	AS-19	A-15	Froðba	Bakkafrost Farming P/F	22-04-2020
0.48	AS-33	A-23	Hvalba	Bakkafrost Farming P/F	22-04-2020
0.97	AS-10	A-52	Oyndarfjørður inni á fjørð	Mowi P/F	22-04-2020
0.30	AS-29	A-89	Velbastað	Luna P/F	21-04-2020

Figure 6. Screen grab of the publicly available portal containing information on sea-lice sorted by date (see hfs.fo)

Escapes and genetic interactions

The fish farmers shall take all measures to prevent incidences with escapes. If there are such events, the fish farmers shall report the events to the authorities, and try to recapture the fish. There is little knowledge of wild salmonids around the Faroe Islands as there have been no national surveys. However, in 2019 surveys on wild trout commenced as a project funded by the fish farmers association.

Nutrient and organic load

Regulations on nutrient and organic load from fish farming is legislated in the environmental protection law (Environmental Protection Act, Løgtingslóg nr 134 frá 29. Oktober 1988).

The farming companies have licences to farm at a set area in the fjord, allowing for movement of the fish farms within the area. All fish farming sites are to have an environmental certificate (Umhvørvisgóðkenning) based on preinvestigations and expected impact.

Monitoring concentrates on the benthic environment, and regulations are based on some elements from the Norwegian standard NS 9410:2016. The seabed at the fish farm is monitored at maximum biomass as a minimum. Thresholds are set for the allowed impact, in form of ph and redox potential and the appearance of the seabed, and also for organic carbon content, zink and cupper. If the thresholds are exceeded the farming company needs to take actions in revised farming plans or reduced biomass.

Future development

Salmon farming already occupies nearly all suitable locations for traditional farming in open net cages on the Faroese coastline. Further expansion will require innovations in farming methods to reduce environmental impacts or development of cage technologies allowing for movement offshore (Young *et al.* 2019).

For further expansion, all three salmon producing companies are concentrating on growing larger smolts, which will spend less time at the sea in order to better utilize the limited number of sites and also to reduce the risk of disease and sea lice infection. Some of the companies are also testing production in highly exposed areas that are unsheltered from the forces of the North Atlantic.

Prior to 2019 the legislation only allowed single species farming in each of the 22 farming fjords, that all were occupied with salmon farming. This has been an obstacle to the development of other aquaculture industries, although a few test licences for seaweed farming have been active. Now the legislation has changed (Regulation on allocation of aquaculture permits) in order diversify the aquaculture industry. In January 2020 five areas were opened for tenders on macroalgae cultivation, and intentions are to open other areas for culturing of various species.

Relevant Aquaculture Legislation and Regulations in force

Relevant Legislation for Aquaculture	
The Aquaculture Act	Løgtingslóg um aling av fiski v.m
Animal Welfare Act	Løgtingslóg djóravælferð (Djóravælferðarlógin)
Animal Disease Act	Løgtingslóg um djórasjúkur
Environmental Protection Act	Løgtingslóg um umhvørvisvernd
Veterinarian Regulations within Aquaculture	
Regulations on disease prevention	Kunngerð um stovnan og sjúkufyribyrgjandi rakstur av alibrúkum
Sea lice regulation	Kunngerð um yvirvøku og tálming av lúsum á alifiski
ISA vaccination regulation	Kunngerð um koppseting fyri ILA (Infectious salmon anaemia, ISA)
Regulation on addressing and monitoring ISA	Kunngerð um niðurberjing og eftirlit við ILA (Infectious Salmon Anaemia, ISA)
Regulation on transportation of aquaculture animals	Kunngerð um flutning av akvakulturdýrum v.m
Regulation on disinfecting outflow from aquaculture facilities	Kunngerð um sóttreinsing av frárensluvatni frá akvakulturbrúkum og akvakulturvirkjum v.m
Regulation on sale, import and export of aquaculture animals and by-products	Kunngerð um sølu, inn- og útflutning av akvakulturdýrum og -úrdráttum Kunngerðum minimumstiltøk í sambandi við niðurberjing av ávísum sjúkum hjá akvakulturdýrum
Other Licence and Management Regulations	
Regulation on allocation of aquaculture permits	Kunngerð um tillutan av aliloyvum
Regulation on tenders for aquaculture licences	Kunngerð um útbjóðing av aliloyvum
Regulation on production of aquaculture in Suðuroy	Kunngerð um virking av alifiski í Suðuroy
Regulation on fees of aquaculture permits	Kunngerð um gjøld fyri aliloyvi

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Germany

Marine aquaculture in Germany is under the legislation of the respective coastal state in case of operations within the 12 nm zone, and under federal jurisdiction in case of (future) operations in the German EEZ.

Although the German National Strategic Plan for Aquaculture Development (NASTAQ, 2014) calls for an expansion of marine aquaculture in Germany, this sector does not show much progress in recent years. It is dominated by mussel production in the North Sea (Table 1), which shows fluctuations over the years mostly due to spat availability. In recent years, production has been increased due to the use of spat collectors. Using the currently licensed area, a maximum annual yield of 40 000 t is expected (NASTAQ 2014). Other mariculture activities such as oyster farming in the North Sea, mussel production and grow-out of large rainbow trout ("Lachsforelle") in the Baltic have a low production volume and do not appear in statistics due to privacy regulations as the number of producers in each sector is too small.

Table 1. Mussel production in Germany 2013 – 2017

Year	No. Operators	Tons
2013	11	5036
2014	11	5280
2015	11	7907
2016	11	13077
2017	11	16856

Data source: Statistisches Bundesamt (DESTATIS), 13.12.2018

In addition, there are a few landbased RAS operations producing marine shrimp (*P. vannamei*) or finfish (*Dicentrachus labrax, Sparus aurata, Seriola sp*.).

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NASTAQ 2014 (Nationale Strategieplan Aquakultur Deutschlands wurde basierend auf dem Beschluss Nr. 36 der Agrarministerkonferenz vom 27.04.2012)

Ireland

Aquaculture Production

Since the initial developments in the early 1970s, the Irish aquaculture industry has grown to become an important contributor to the economy of coastal areas. There has been a steady increase, in both output and value. The diversity of sites used and the species farmed have also increased. The sector has grown in output value from €37.2 million (26,500 tonnes) in 1990 to €179 million (37,206 tonnes) in 2018 (Figure 1). The industry currently employs 1,077 FTE.

Aquaculture output up to 2018 has been variable and has ranged from 30,000 to 50,000 tonnes in the last 10 years. It remains mainly export-driven, marine based, with a smaller land-based, freshwater aquaculture sector. Fluctuation in production, over the last 10 years, is predominately due to production variations for salmon sea-farms, and to a lesser extent, the volume of bottom grown mussels produced. Overall, while production value has seen a net gain despite limitations to output capacity, linked to licensing and consequent reductions in salmon production. This value growth was made possible by steady increases in the unit value of product driven by a growing recognition of Irish product quality and provenance through the achievement of international certifications such as MSC, and Organic Labels.

Mussels (*Mytilus edulis* - bottom and rope grown), Pacific oysters (*Crassostrea gigas*), native oysters (*Ostrea* e*dulis*) comprise almost 100% of the production of shellfish. Some operators are licenced for clams, scallops, abalone and sea-urchins, but production has ceased or is very low. Mussels, which are farmed using both suspended ropes (intensive) and bottom-culture (extensive), in 2018 accounted for 57%, by volume, of annual shellfish production. Oysters (principally Pacific oysters) account for a further 42%. Shellfish farming is practised in all coastal counties (bar 3).

Salmon and rainbow trout are the two principal species farmed at sea. In 2018, Salmon accounted for 94%, by volume, of annual finfish production. The rest of the production is divided between freshwater species (mostly trout) and ova and smolt sales from hatcheries. Finfish farming is restricted to five western seaboard counties – Donegal, Mayo, Galway, Kerry and Cork.

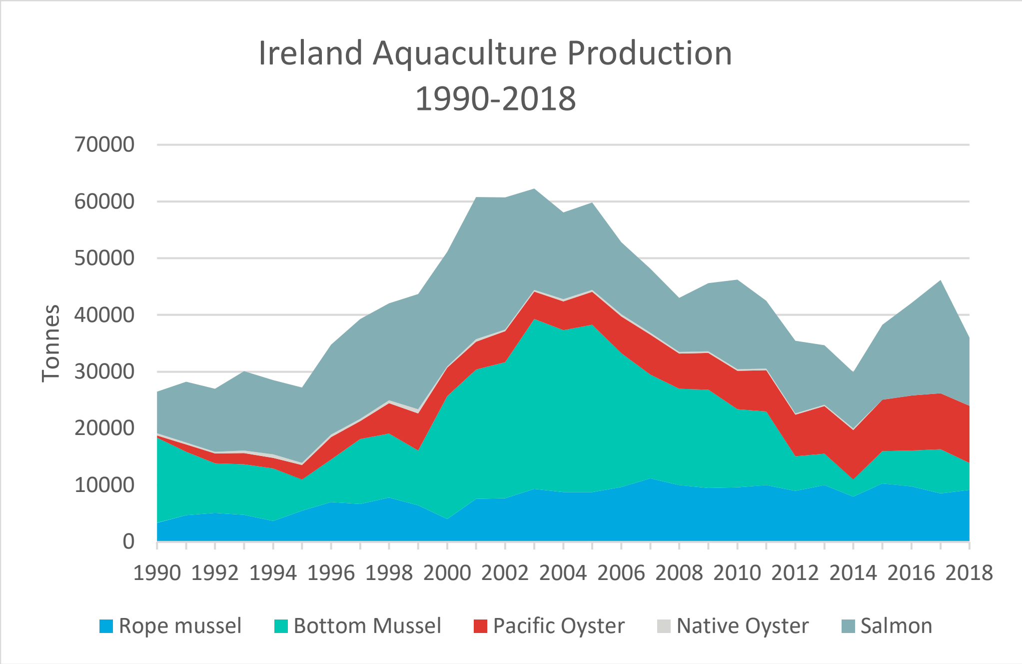

Figure 1. Aquaculture production for dominant species - 1990-2018

Licencing

Aquaculture activities in Ireland licenced under the Fisheries (Amendment) Act 1997 and administered by the Department of Agriculture Food and the Marine. A backlog in the processing of aquaculture licence applications developed on foot of a 2007 European Court of Justice (ECJ) judgement against Ireland for breaches of the EU Birds and Habitats Directives. An element of the judgement concerned a failure by the State to put in place a system for adequate assessment of aquaculture licence applications in NATURA 2000 sites. In response to the judgement a plan in response was prepared and implemented. The process includes data collection, the setting of Conservation Objectives by the National Parks and Wildlife Service (Conservation Agency), identifying the scientific interests to be protected in the bays, carrying out of Appropriate Assessments of the licence applications against those conservation interests and appropriate licensing.

The production of these Appropriate Assessment reports has been resource intensive and time consuming, not least because of tidal cycles and seasonality issues in relation to data gathering habitats and migratory species of birds and other environmental events. Profiling of aquaculture activity has had to be carried out for all operations in designated bays in order to define the likely interaction between aquaculture activities and conservation features. All of this preliminary work was conducted to prepare the foundation for the consideration of licence applications was carried on from 2009 onwards. As illustrated in Figure 2, the Ireland has made over 1,200 licensing determinations since 2012.

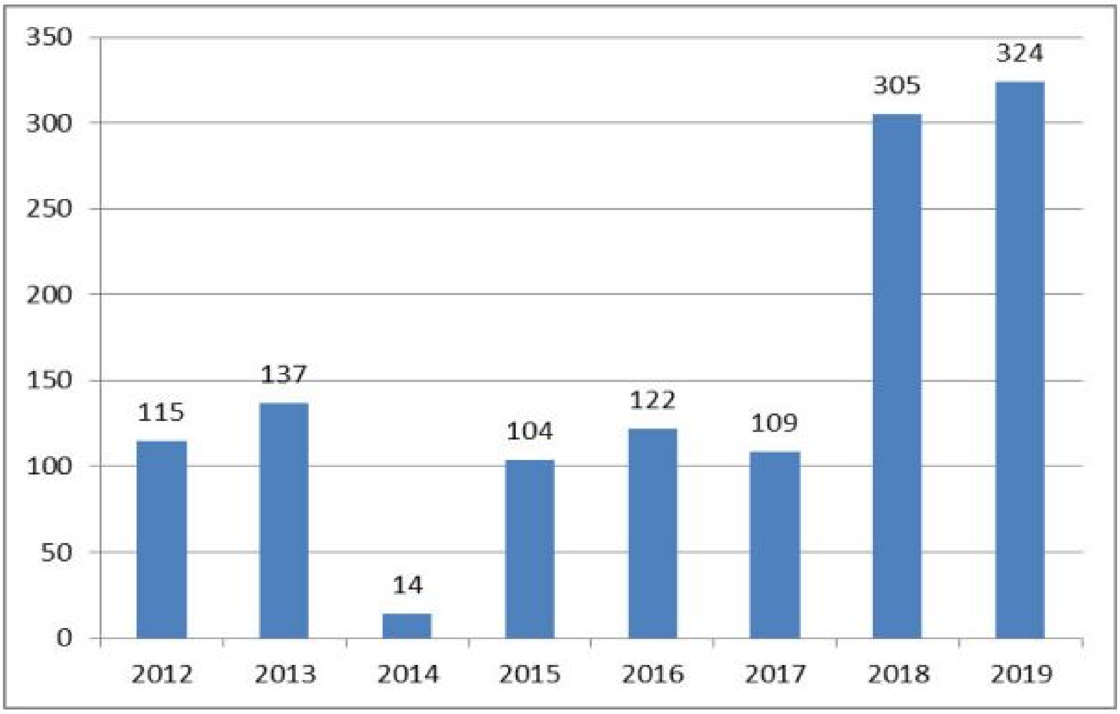

Figure 2. Aquaculture Licence Determinations 2012 – 2019 (source DAFM[46])

[46] https://www.agriculture.gov.ie/media/migration/aboutus/ministerialbrief/2020/BusinessArea4SeafoodSector170920.pdf

Norway

Production statistics and trends

Aquaculture has become an important industry in Norway and in 2019 the export value of farmed Atlantic salmon and rainbow was 76 billion Norwegian kroner (NOK) and this accounted for 71% of the total export value of seafood from Norway (Source: Norwegian Seafood Council).

Atlantic salmon is the major aquaculture species, and the production of this species has been steadily rising since the mid-1980s, but has flattened out at around 1.2-1.3 million tons since 2012 (Figure 1).

The aquaculture production in 2019 for the following species were; Atlantic salmon: 1 357 304 tons, rainbow trout: 82 855 tons, brown trout: 199 tons, Atlantic halibut: 1524, Atlantic cod: 896 tons (production based on wild-caught fish), arctic char: 365 tons, other fish species: 296 tons, blue mussels: 2134 tons, oysters: 7 tons, other molluscs and crustacean: 8 tons (Source: Directorate of Fisheries, Norway).

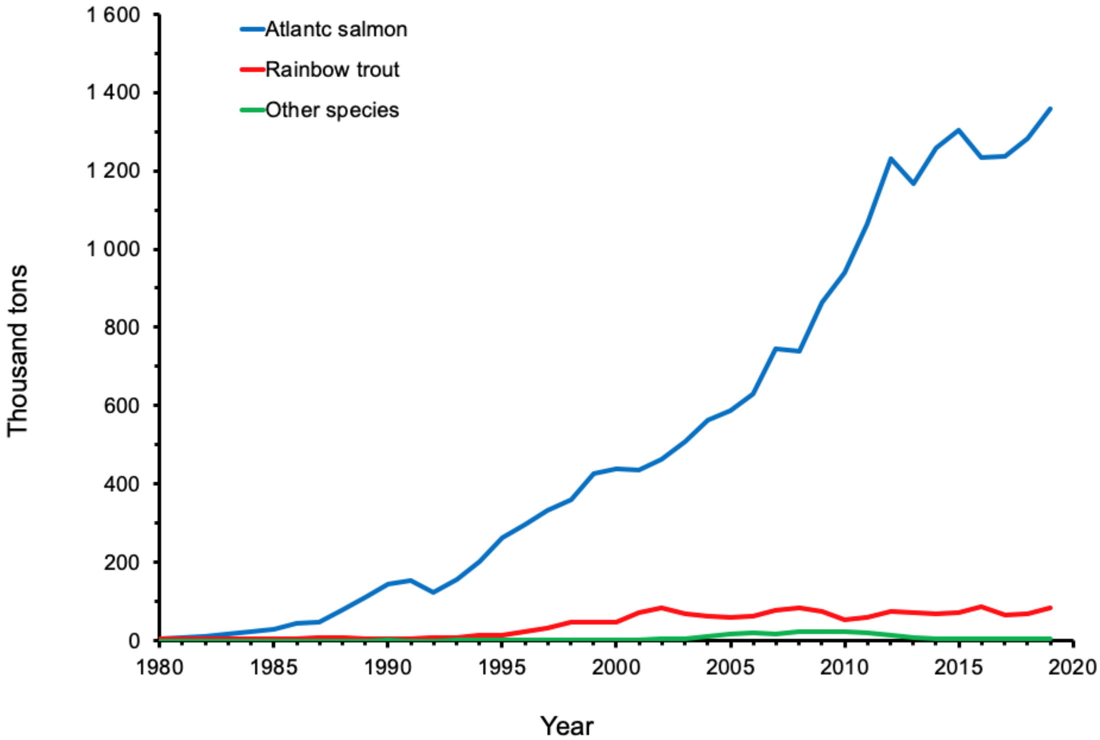

Figure 1. Production of Atlantic salmon, rainbow trout, other marine fish species and blue mussels in Norway during 1980-2019. (Preliminary data for 2019; metric tons round weight). Source: Directorate of Fisheries, Norway.

Governance of aquaculture

Basically, aquaculture in Norway is a permit-based industry and are thus prohibited unless a specific license is given. While the Norwegian aquaculture industry is dominated by production of Atlantic salmon and rainbow trout in sea cages, there are also several special licenses for Atlantic salmon, trout and rainbow trout; for example, viewing permits, research permits and teaching permits. Permits for juvenile production, broodstock and slaughterhouse also fall under special permits, as well as aquaculture of other species of finfish, crustaceans, algae and molluscs.

For Atlantic salmon we have currently (May 2020) 1377 permits including commercial production, R&D, broodstock and juvenile production. In the sea, 980 sites are cleared for production of Atlantic salmon, trout and rainbow trout. In addition, there are 784 licenses for production of other species (fish, invertebrates and algae).

There has also been a specific system granting special licenses for development of novel technologies aiming to solve specific environmental challenges like salmon lice, escapees or areal restrictions.

Permits for aquaculture are normally granted on an ongoing basis through application. However, permits for commercial food-production for Atlantic salmon, trout and rainbow trout in seawater are limited, and ordinary growth in production volume is regulated from the Ministry of Trade, Industry and Fisheries through specific regulations. Furthermore, aquaculture production may not start until a specific site is cleared for use with a specified limit of production volume. The localization and clearance of farm-sites are the responsibility of the County Governor, who consider local area regulations, environmental carrying capacity on the site and issues discharge licenses for each site.

Currently, increase in the commercial production of Atlantic salmon, trout and rainbow-trout is regulated through a "traffic-light system", where effects from salmon lice on wild populations of salmonids (currently only Atlantic salmon is included) regulating growth in production. The coast of Norway is divided into 13 production zones, and within each zone the impact on the wild salmon is assessed through a combination of field-surveillance and modelling of salmon lice dispersion. Based on predefined levels of lice-induced mortality, the production area get green (<10%), yellow (10-30%) or red light (> 30%) which in turns give the farmers an opportunity to buy 6% increase in production volume if green, and a 6% reduction in red areas. Yellow areas keep the present production volume. For more details see Produksjonsområdeforskriften (2017).

Management tools for development of sustainable aquaculture, and regulations

For salmon farming in open sea cages, a number of potentially harmful effects may impact the surrounding ecosystem as transfer of parasites, bacteria and viruses to wild populations, genetic impacts of wild salmon stocks, effects of nutrient and organic particle emissions, effects of therapeutics and toxins on non-target organisms and ecological interactions with wild species (Taranger *et al.*, 2015, Grefsrud *et al.*, 2018; 2019; 2020, Figure 2).

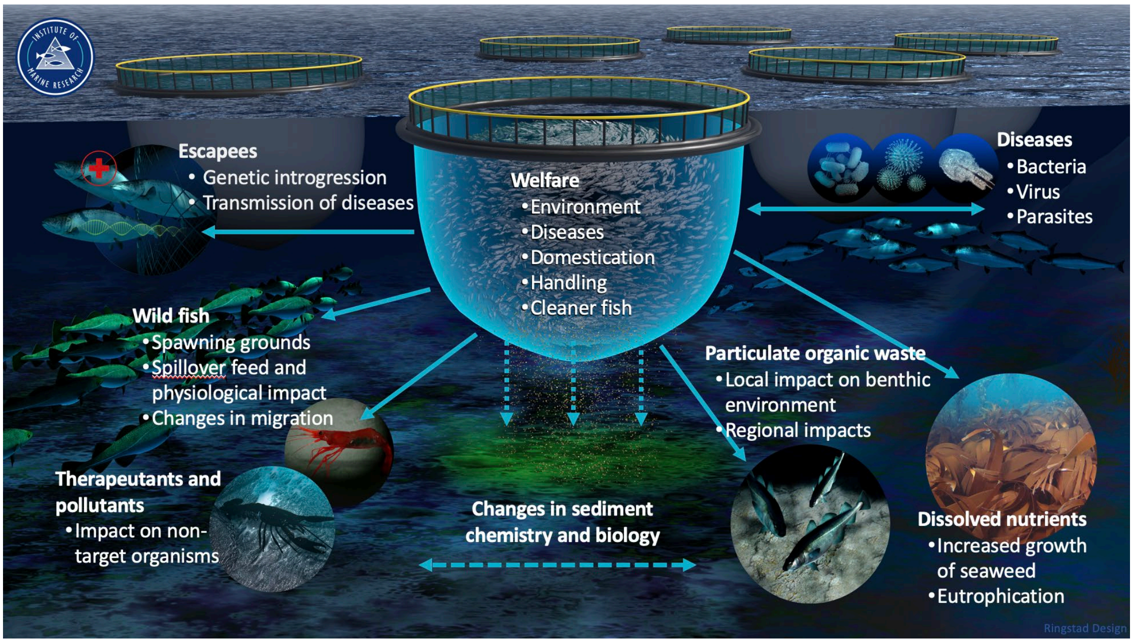

Figure 2. Environmental impacts of fish farming in open net pens and identified risk factors (Grefsrud, IMR, 2019).

A main objective of the aquaculture governance in Norway is to develop management tools to allow development of sustainable aquaculture. For each of the risk factors identified for finfish (Chapter 3; Figure 2) and shellfish (Chapter 4), responsible agencies, laws and regulations, monitoring, mitigation, and knowledge gaps are summarized in Annex 4 (finfish) and Annex 5 (shellfish).

Important risk factors have been identified and described (St. Mld. St 16 (2014-2015) 2016), 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 production zones (Produksjonsområdeforskriften 2017), escapes and genetic impacts in salmon rivers (Kvalitetsnorm for ville bestander av Atlantisk laks, 2013; Forskrift om fellesansvar for utfisking mv. av rømt oppdrettsfisk, 2015); and emissions and organic impact at the production site and surrounding areas (Forskrift om rammer for vannforvaltningen, 2006; Miljøovervåkning av bunnpåvirkning fra marine akvakulturanlegg, 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.*, 2019).

The Norwegian legislation ensures good fish health by preventing the pathogens to be introduced or spread, e.g. by import or transmission between farms. National surveillance programs and mandatory, frequent fish health controls contribute to detect diseases.

Though, if pathogens are introduced and create problems in farms or areas, the legislation, inspections, samplings and contingency plans will contribute to conduct adequate measures.

Future development

Further increase of farming of Atlantic salmon and rainbow trout is today mainly limited by negative impact on wild salmonids from sea lice from aquaculture production (Taranger *et al.*, 2015; Grefsrud *et al.*, 2018; 2020). Growth are only allowed in green areas (sea-lice induced mortality < 10%), while production in red areas (sea-lice induced mortality > 10%) must be reduced, and the production capacity in each of the 13 production areas (Figure 3) are assessed every two-year from 2017 (Produksjonsområdeforskriften, 2017), Figure 4.

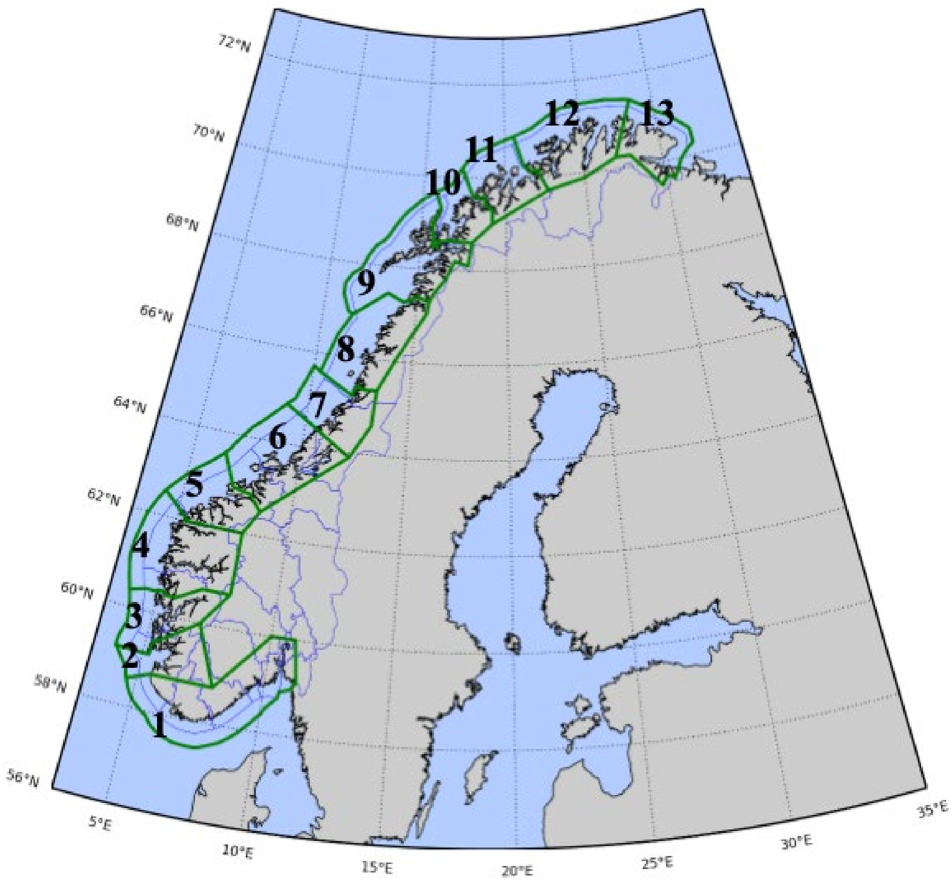

Figure 3. The geographical division of the 13 production areas for Atlantic salmon and rainbow trout in Norway. Source: https://lovdata.no.

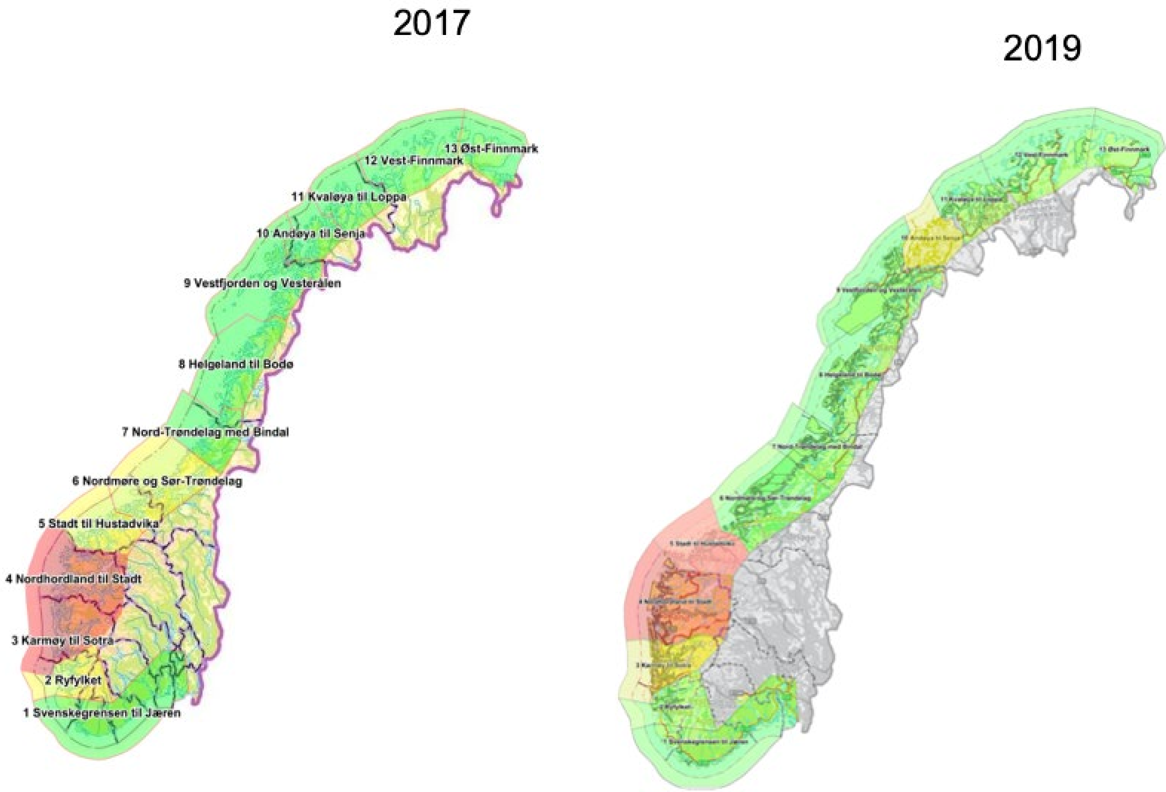

Figure 4. Traffic light results for the 13 production areas in 2017 (www.regjeringen.no/no/aktuelt/regjeringen-skrur-pa-trafikklyset/id2577032/) and 2019

www.regjeringen.no/no/aktuelt/regjeringen-skrur-pa-trafikklyset-i-havbruksnaringen/id2688939/

The aquaculture industry works in close collaboration with research institutions to reduce environmental impacts, and there is being developed a number of new technologies such as closed tanks, sterile fish, various methods to prevent infestation, the use of cleaner fish. Great progress has been made, but it is particularly important to clarify whether new forms of production provide acceptable fish welfare (Grefsrud *et al.*, 2019).

According to the Norwegian Government's new marine strategy, farming of other species than salmon and trout are encouraged. In addition to other fish species, low trophic animals as molluscs and other filter-feeders, seems to have the largest potential. It is a global need to produce more food from the sea, but an increased diversity within the aquaculture industry will also be able to supply raw materials to other types of industry, such as feed production, the pharmaceutical and cosmetics industry and the production of biofuels. When starting new species in aquaculture it will be important to follow up with research aimed at environmental effects to ensure sustainable development of the industry.

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Portugal

Production statistics and trends

Portugal is located in Southwestern Europe, at the western end of the Iberian Peninsula and is also comprised of the autonomous regions of Azores and Madeira, located in the Atlantic Ocean. Coastal continental Portugal is bordered by the North Atlantic Ocean notwithstanding some influence of the Mediterranean Sea on the south coast. Portuguese aquaculture is mainly characterized by extensive and semi-extensive systems located in coastal lagoons, estuaries and transitional waters along the coast. Intensive regimes consist of sea cage systems and land-based operations, as well as the majority of freshwater fish production operations. Portugal has the highest seafood consumption of the EU with 61.5 kg *per capita*, (Guillen *et al.* 2019) while the EU average sits at 27 kg *per capita*. In 2018, Portuguese aquaculture production reached 13,992 t (average 2010-2018 was 10,778 t), with more than 90% produced in brackish/salt water (Figure 1).

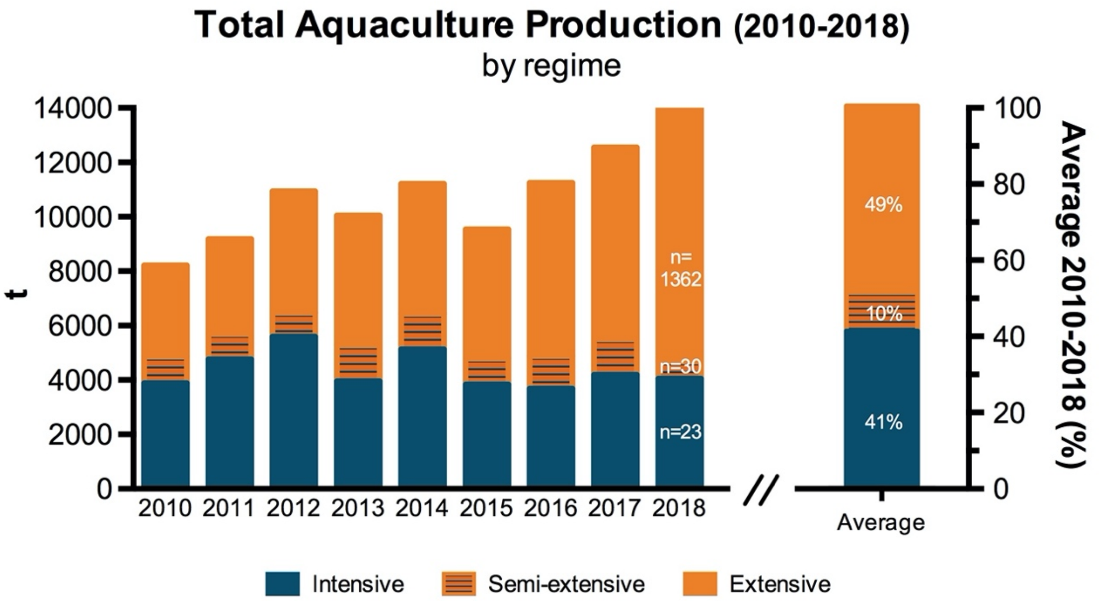

Figure 1. Total aquaculture production evolution in Portugal from 2010 to 2018 (in metric ton), and average from 2010 to 2018 (in %), separated by intensity regime and correspondent number of operations registered as active in 2018.

With this volume of production, Portugal has been oscillating in the last years between the 13th and 17th biggest productions in the EU. Latest statistics relative to 2018 can be found in the official document "*Estatísticas da Pesca* - 2019" (direct link in References), published by Statistics Portugal (INE; www.ine.pt) and the Directorate for Natural Resources, Safety and Maritime Services of the Portuguese Government (DGRM; www.dgrm.mm.gov.pt). In 2018, 1415 operations were registered as active, only two of which classified as reproduction units. In terms of farming regime, 1362 were extensive, 30 semi-extensive and 23 intensive, although corresponding to 66%, 5% and 29%, respectively, of total production. In terms of major groups of species, molluscs with 67%, followed by marine fish with 28%, dominated the production (Figure 2). The remainder of the production came from freshwater fish (Salmonids) with 5%, and crustaceans and algae with a residual combined contribution below 1%. Mollusc production was mainly dedicated to clams (3970 t; *Ruditapes decussatus*), mussels (1746 t; *Mytilus* ssp) and oysters (3451 t; *Crassostrea* spp, *Ostrea edulis*). Marine fish production was mainly dedicated to turbot (2582 t; *Psetta maxima*), gilthead sea bream (896 t; *Sparus aurata*) and European sea bass (200 t; *Dicentrarchus labrax*), with species like meagre (*Argyrosomus regius*) and sole (*Solea* ssp) contributing collectively to the remainder of the production. Freshwater fish production was 94% trout (665 t; *Oncorhynchus mykiss* and *Salmo trutta fario*).

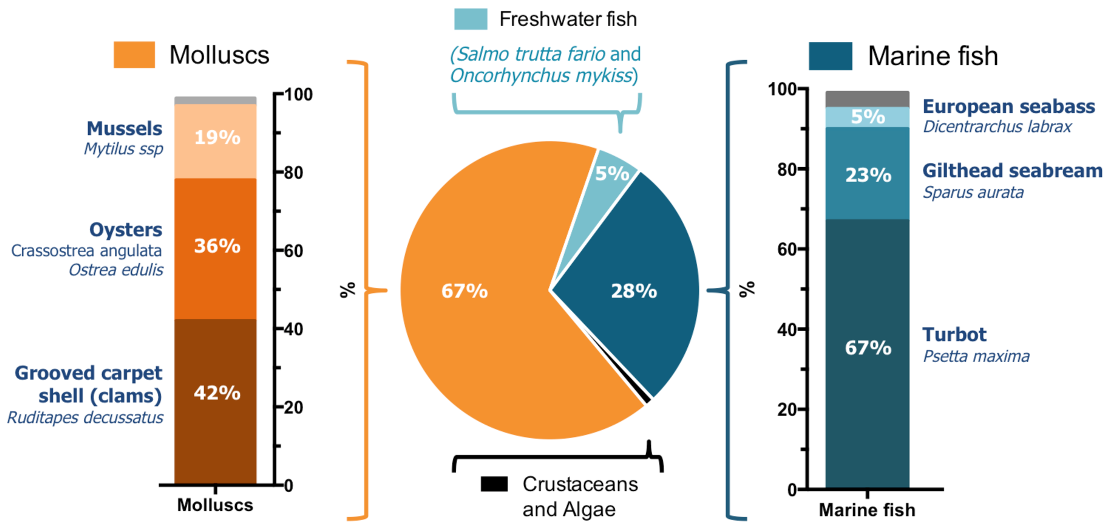

Figure 2. Total aquaculture production in Portugal in 2018 by group of species (central pie chart; in %), and main species produced within each group (in %; grey bars: other species).

Governance of aquaculture

Strategic plan

Within the National Strategic Plan for the Sea 2013-2020 (ENM-2013-2020) elaborated by the Portuguese Government it was established as an objective the promotion of aquaculture. From this structural document stemmed the Strategic Plan for Portuguese Aquaculture 2014-2020 (PEAP-2014-2020) where several points were identified as critical to increase and diversify national aquaculture production. Those encompassing administrative procedures needed to license an aquaculture operation were revised, reduced and/or simplified, namely the legal framework for water use and the legal framework for private use of maritime space. This led to a general review of the national maritime space with the scope of granting utilization rights for aquaculture operations, but also for other purposes (exploitation of renewable energies, prospecting and exploitation of gas and oil, scientific research, recreation, sports and tourism, dredging, etc.). This review would also allow compatibility with local authority planning and protected areas. The legal framework for granting licenses for private use of the national maritime space (TUPEM; *Título de utilização privativa do espaço marítimo*) was revised in DL38/2015. To ensure the maintenance of the physico-chemical and biological conditions of the marine environment and to ensure the removal of constructions and mobile structures in the area or volume that the TUPEM affects, ordinance P125/2018 established the arrangements and amount for its security deposit.

Licensing

In order to organize and facilitate the granting private use of the national maritime space for aquaculture purposes, the legal framework for granting an aquaculture activity license (TAA; *Título de Atividade Aquícola*) was gathered in a single final document (DL40/2017) which establishes the basic legislation on aquaculture. Similarly to DL38/2015, the 22nd article of DL40/2017 determines that the granting of the TAA is conditional to the provision of a security deposit. Ordinance P276/2017 establishes the arrangements and amount of the security deposit needed to ensure good ecological condition for the environment and water bodies as well as the removal of any infrastructure at the end of the TAA.

The procedure for licensing is coordinated by the DGRM for aquaculture operations in marine waters, including transitional waters and related establishments, and by the Institute for Nature Conservation and Forestry (ICNF; www.icnf.pt) in inland waters and related establishments. Additionally, the Portuguese Environment Agency (APA; www.apambiente.pt) and the Directorate for Veterinary Services (DGAV; www.dgv.min-agricultura.pt) should be consulted in every procedure mainly to intervene on the Environmental Impact Assessment and to evaluate matters of food security, respectively. The consultation should be extended to: the Port and Maritime authorities if within their jurisdiction and/or interfering with naval transport; the Institute of the Sea and Atmosphere (IPMA; www.ipma.pt) if at sea; and the Institute for Conservation of Nature and Forestry (ICNF) if in classified areas (DL142/2008) or interfering with protected species (DL316/89).

Moreover, DR9/2008 also applies to all offshore aquaculture, where recommendations for monitoring environmental quality parameters were established. These include granulometry of superficial sediments, sediment organic content, source of organic matter, benthic macroinvertebrates (composition, abundance and biomass), specific composition, structure, density, biomass, trace metals, residence time and demographic aspects of the ichthyological communities. Specific requirements concerning other regulations may be requested during the process of granting a TAA, particularly to be included in the Environmental Impact Assessment notwithstanding that many of them already converged with European regulation (e.g. alien and locally absent species in aquaculture - EC 708/2007; organic production - EC 889/2008; 710/2009; food safety - EC 852/2004; 853/2004; 854/2004, etc.). Even if under a single decree (DL40/2017), aquaculture intersects with many other legislations.

Operational plan

All information and procedures (national strategy, statistics, legislation, mapping, etc.) regarding aquaculture were centralized into a single platform (https://www.dgrm.mm.gov.pt/en/aquicultura1). Submission of documentation can now be made electronically submitted on an online platform. In order to manage and follow the evolution of the private use of maritime space the Portuguese Government developed one main management tool based on mapping of areas associated with authorized aquaculture farms (active and inactive). MAR2020 is a joint effort with the objective of fostering environmentally sustainable, resource-efficient, innovative, competitive and knowledge-based aquaculture. The European Maritime and Fisheries Fund (EMFF) supported with approximately 59 M€ the development of joint support facilities and infrastructures, investments aiming to increase the efficiency of aquaculture units, promotion of aquaculture products in new markets and the development of maritime spatial planning. Additional 19.6 M€ were added from the Portuguese National Budget.

Possible improvements

Despite all efforts to centralize information and administrative procedures, Environmental Impact Assessment is still organized on a case-by-case basis, which may intersect with other regulations. For the time being, granting of TUPEM or TAA is not conditioned by quantitative regulations (concentrations, ranges, or thresholds for any parameter) although some recommendations are in place (DR9/2008 for offshore aquaculture). It is worth noting that most operations in Portugal are extensive or semi-extensive and for bivalve mollusc species located in coastal lagoons, estuaries and transitional waters along the coast. Some of these operations still follow traditional, low impact farming practices for which strict and controlling environmental scrutiny have not been demanded. Nonetheless, these operations may develop conflicting interests with dense populations, touristic activities, other farming activities (e.g., rice) and naval traffic.

Future development

Limitations for further growth

If intended to increase productivity, most extensive and semi-extensive operations would require structural improvements in order to become less vulnerable to low hydrodynamics, eutrophication processes, and to long-term extreme weather events such as drought and floods, which significantly alter water supply in both quality and volume. Some of those improvements could be difficult to license since most locations are already within protected areas with limited margin for growth. For this reason, recently, offshore operations came into effect: 1) in the South coast with several established floating platforms for molluscs and some tuna ranching; 2) off the coast of Aveiro a TUPEM was filed under a joint industry-university research project for Atlantic salmon for 12 months; 3) in the south coast of Madeira, several locations have been tested for gilthead sea bream cages. Intensive seacages for sea bass were also implemented in the port of Sines, making the best out of increased water temperatures resulting from cooling processes of a nearby refinery/petrochemical industrial complex. These operations may reshape Portuguese aquaculture in the years to come and should be followed closely from an environmental point of view. The viability of these locations for fish species are yet to be determined, meaning that species selection, farming processes and logistics are far from being considered optimal. Generally, the selection of farming locations is intimately connected and ultimately determines the farming system and species. Portuguese aquaculture is in this aspect very limited and thus, land-based aquaculture, particularly in recirculated aquaculture systems (RAS), may have enough margin to grow with fewer risks. Unable to compete with other countries that have specialized over the years in producing enormous volume for one or two species, Portuguese aquaculture, due to favourable temperatures all year-round, should diversify and aim at land-based "niche" aquaculture (e.g. seaweed, sea urchins and novel fish species such as meagre *Argyrosomus regius*). This could circumvent many of the problems already described for offshore intensive farming: escapees and interactions with native populations, disease outbreaks, poor control over wastewaters, impact on benthic communities and marine mammals, etc. Within this diversification strategy, allied to land-based systems, arises also the possibility to integrate farming systems (IMTA and aquaponics).

Knowledge gaps

From the SWOP analysis performed in the PEAP-2014-2020 several weaknesses were identified and addressed as already described above (e.g. planning and identification of areas for aquaculture with the creation of GeoPortal for aquaculture; delays and complexity of licensing processes and access to public support schemes with the creation of the legal framework DL40/2017 and centralization of information and licensing procedures). Most analyses were administrative rather than science-related, which in the incipient state of Portuguese aquaculture could alone, in short term, be responsible for the increase in production. However, without a set long-term strategy becomes difficult to indicate main knowledge gaps.

On the one hand, it is uncertain if the recent bid on offshore aquaculture has been supported by appropriate research. Choice of location may be the initial challenge, especially when faced with rough Atlantic conditions. Funds, specialized human resources and conditions to access, sample and monitor those locations could be considered as an integral part of that challenge. Then, how consequences unfold from intensive farming strategies in these locations, as thoroughly described in other countries, are yet to be anticipated and laid down into regulation. If the industry is indeed directed towards land-based aquaculture searching for diversification, knowledge gaps sit on understanding and controlling the life cycle of selected species, establish constant supply of fingerlings or seed through hatcheries and well-designed trait-selection programmes. Also, diet optimization with focus on nutrient cycling (reduced waste from faeces and reduced ammonia production from protein catabolism), water circulation and energetic efficiency of RAS should be considered priorities. As sanitary control should be easier to supervise in this setting, vaccination and/or antibiotic treatments should be registered and reported to the authorities resulting in better animal-health practices and improved credibility before public opinion. In a country where the majority of the seafood consumed still comes from captures, transparency and awareness should be conjugated with better marketing and distribution strategies in order to develop differentiated products for niche markets. Innovative farming and processing techniques could also increase the economic and social positioning of aquaculture in Portugal. Labels for sustainable production and provenience/authenticity certificates should be adopted to promote confidence and loyalty of consumers. This will require that farmers and their associations, scientific and technical institutions and processing industry share experience and decrease the chances of failure by permanent cross-talk with Governmental institutions.

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Abbreviations (from Portuguese origin)

- ASAE - *Autoridade de Segurança Alimentar e Económica* (Food Safety authority; www.asae.gov.pt)
- APA - *Agência Portuguesa do Ambiente* (Portuguese Environment Agency; www.apambiente.pt)
- DGAV - *Direção Geral de Alimentação e Veterinária;* (Directorate for Veterinary Services; www.dgv.min-agricultura.pt)
- DGPA - *Direcção-Geral das Pescas e Aquicultura* (Directorate for Fisheries & Aquaculture of the Portuguese Government)
- DGRF - *Direcção-Geral dos Recursos Florestais* (Directorate for Forestry Resources)
- DGRM - *Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos* (Directorate for Natural Resources, Safety and Maritime Services of the Portuguese Government; www.dgrm.mm.gov.pt)
- DL- *Decreto de Lei* (Law Decree)
- DR - *Decreto Regulamentar* (Regulatory Decree)
- DdR - *Declaração de Retificação* (Rectification Statement)
- ICNF - *Instituto da Conservação da Natureza e das Florestas* (Institute for Nature Conservation and Forestry; www.icnf.pt)
- INE - *Instituto Nacional de Estatística* (Statistics Portugal; www.ine.pt)
- P - *Portaria* (Ordinance)
- RCM - *Resolução do Conselho de Ministros* (Ministers' Council Resolution)
- TAA - *Título de Atividade Aquícola* (License for Aquaculture Activity)
- TUPEM – *Títulos de Utilização Privativa do Espaço Marítimo* (License for Private Use of the National Maritime Space)

United Kingdom

Production statistics and trends

A brief description of the aquaculture industry by country: Types of aquaculture, production statistics and trends.

In 2016, the UK aquaculture industry reported production of 194,509 tonnes (with an estimated first-sale value of £839 million) and employment for 3,285 people. The UK aquaculture industry is diverse, producing a variety of finfish and shellfish species for direct consumption, as functional species (cleaner fish), restocking fisheries (trout and coarse fish species), and the ornamental (pet) trade. The majority (95%) of reported UK production is from the marine environment (although production tonnage statistics exclude freshwater smolt reported by number). No aquaculture production of seaweed has yet been reported in the UK, although research trials are underway.

Table 1. Reported UK aquaculture production tonnages for 2016 (the latest available for the whole UK).

	Species	tonnes	% UK total	% Marine
Marine environment: Finfish	Atlantic salmon	163,135	84%	89%
	Rainbow trout	3,759	2%	2%
	Atlantic halibut	67	0%	0%
	Ballan wrasse	4	0%	0%
	Lumpfish (=lumpsucker)	10	0%	0%
Marine environment: Shellfish	Blue mussels	14,685	8%	8%
	Pacific cupped oyster	2,166	1%	1%
	European flat oyster	23	0%	0%
	Queen scallop	6	0%	0%
	Great Atlantic scallop	4	0%	0%
	Clam species	6	0%	0%
Freshwater environment: Finfish	Rainbow trout	10,092	5%	
	Brown trout (=Sea trout)	299	0%	
	Other trout (Arctic char, brook trout, hybrid trout)	23	0%	
	Common carp	171	0%	
	Other freshwater fish	58	0%	
Total		194,507	100%	

While freshwater finfish production occurs throughout the UK, marine finfish production is largely located in Scotland, with production predominately (>99%) in net-pens. Atlantic salmon comprises the bulk of production, with rainbow trout and halibut also farmed (Figure 1). Since 2008, salmon production has increased, marine-grown rainbow trout production has been variable, and halibut production has decreased. Production of cleaner fish (ballan wrasse, lump-fish) has begun in recent years, with production largely reported by number (rather than tonnage). Minor marine production of other finfish species has also occurred (e.g. sea bass, cod, turbot) but not in recent years.

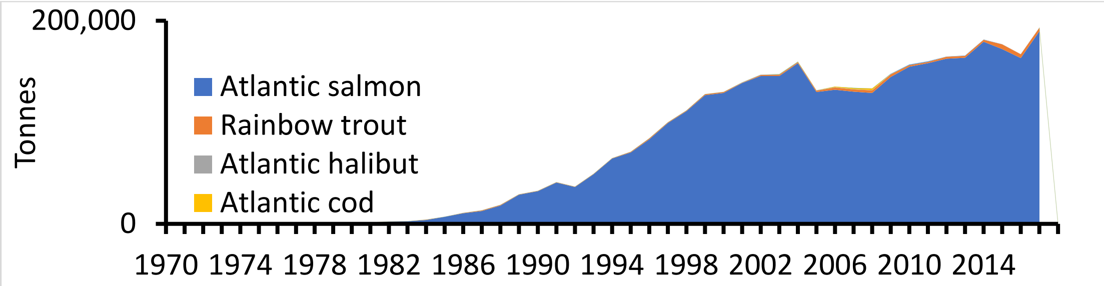

Figure 1. UK production trends in marine finfish. N.B. The contribution of other species is barely discernible due to the dominance of Atlantic salmon.

Marine shellfish aquaculture is located across the devolved nations within the UK, with blue mussels and Pacific cupped oyster being the key species. Mussels are produced from subtidal suspended systems (longline and raft) and on-bottom production, while all oyster production is reported as intertidal on-bottom (inc. sur-elevated on trestles). Since 2008, reported production has decreased for mussels, increased for Pacific cupped oyster, and decreased for the native European flat oyster (Figure 2).

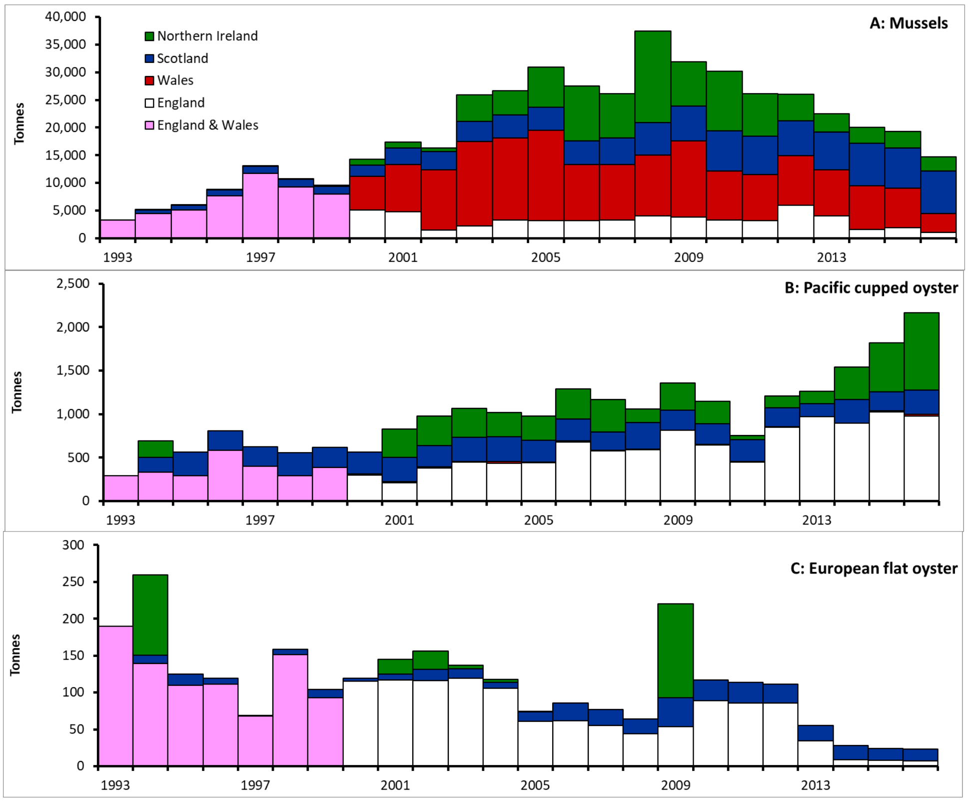

Figure 2. UK production trends in marine shellfish production by nation.

The UK's Multiannual national plan for the development of sustainable aquaculture set an aspirational 2020 target for aquaculture production to increase 254,000 tonnes, via a 22% increase in (marine) finfish and 33% increase in marine bivalves. Current trends indicate a significant shortfall, particularly in shellfish production.

Governance of aquaculture in the UK

Aquaculture in the UK is governed under 4 separate jurisdictions; England, Scotland, Wales and Northern Ireland, with differing legislative requirements in each. In each country there is a process through which permission and licenses are required but can vary between jurisdiction. However, there are generally five stages to the application in each jurisdiction. An example of the application and licensing process for Scotland which accounts for approx. 87% of aquaculture production in the UK is given in Figure 3, though this is a template for UK licensing

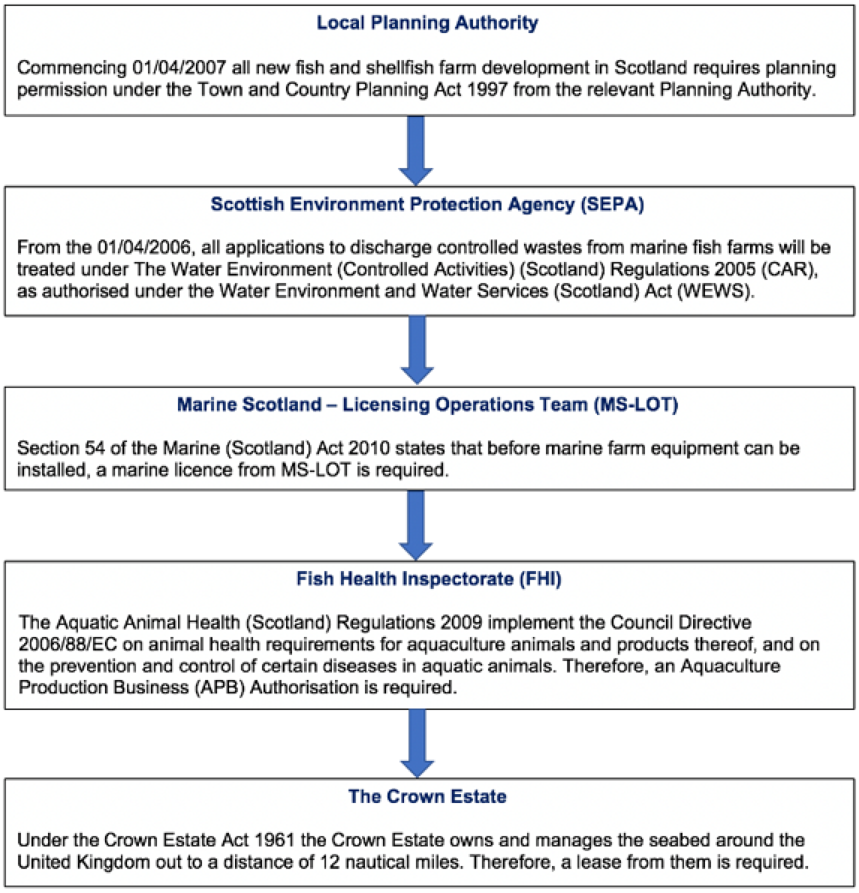

Figure 3. An example of the licensing process for a marine fish farm in Scotland (Marine Scotland, 2016).

1) Planning permission

Planning permission is sought from the local authority in England, Wales and Scotland. In Northern Ireland Planning permission is from the Department of the Environment Planning Service (land-based sites only). A local authority (or planning authority) is responsible for determining planning applications for new finfish and shellfish farms or modifications to existing farms.

In England there is no requirement for an EIA for shellfish. For finfish there are specific thresholds (i.e. for finfish its 10 tonnes for terrestrial and 100 tonnes for Marine). Activities would also need to comply with environmental regulations if in an area of statutory protection and will need to be consented and/or assessed accordingly by the Competent Authority.

In Northern Ireland the EIA comes under the Environmental Impact Assessment (Fish Farming in Marine Waters Regulations (Northern Ireland) 2007 (marine finfish farms only). The competent authorities in Wales are the Welsh Government and NRW (Natural Resources Wales).

In Scotland, most finfish farm planning applications require an EIA. When considering an application for a fish farm, the local authority will seek advice from Marine Scotland, SEPA, Scottish Natural Heritage, Historic Scotland, and local District Salmon Fishery Boards, on potential impacts of the development on water quality, interactions with predators, wild salmonids, species and habitats, conservation areas, landscape, marine cultural heritage, noise, and waste. Other interested parties may also provide comment to the council for consideration at this time. Scottish fish farm operators require planning permission before undertaking any activities which may affect the water environment, and local Authorities grant planning consent for Marine and freshwater fish farms (both shellfish and finfish) under the Town and Country Planning Act 1997.

2) Environmental license

Water abstraction or usage licences are required in all jurisdictions. In Scotland where the main form of aquaculture is marine cage farming of salmon a discharge consent is required.

Water discharge consent and abstraction licence from the Northern Ireland Environment Agency Water Management Unit. Marine Licences are from the Department of the Environment Marine Division in the case of marine finfish farms.

In Wales, abstraction and discharge licences are issued by NRW. Consent for discharges from a fish farm, or a Marine Licence for discharge from a boat are required.

Water abstraction or discharge into water in Scotland is covered by the Water Environment Controlled Activities Scotland Regulations 2011 (CAR). Regular monitoring of water quality, including discharges from fish farms, is carried out by SEPA again under the Water Environment Controlled Activities Scotland Regulations 2011 (CAR). All fish farms operators must obtain a CAR licence, which sets limits for discharges in its consent conditions. Routine inspections are carried out for conformity to all environmental regulation, including the provisions of the Water Framework Directive and related permissions and controls, and submitted to SEPA.

In England abstraction and discharge is regulated by the Environment Agency under the Environmental permitting regulations (E&W) 2010.

3) Permits.

This depends on the aquaculture activity, but if it is offshore (fish or shellfish) then it requires a permit. In Scotland, Marine licences are issued by the Marine Scotland Licensing Operations Team (MS LOT).

In Northern Ireland, Marine Licences are from the Department of the Environment Marine Division in the case of marine finfish farms.

4) Animal Health and Welfare

In England and Wales authorization by the Fish Health Inspectorate is needed under Aquatic Animal Health (England and Wales) regulations 2009 and the Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011 if applicable.

Authorization by Marine Scotland is under the Aquatic Animal Health (Scotland) Regulations 2009; routine inspections are undertaken by the Marine Scotland Fish Health Inspectorate for conformity with all statutory requirements under the Animal Health and Welfare (Scotland) Act 2006. Fish Health inspectors conduct a statutory inspection and sampling programme and are appointed by the Scottish Ministers under the fish health legislation. This legislation includes: The Aquatic Animal Health (Scotland) Regulations 2009 (implementing Council Directive 2006/88/EC), The Fish Farming Businesses (Record Keeping) (Scotland) Order 2008, The Aquaculture and Fisheries (Scotland) Act 2007, amended by The Aquaculture and Fisheries (Scotland) Act 2013, Trade in Animals and Related Products (Scotland) Regulations 2012 and The Sea Fisheries (Shellfish) Act 1967. The fish health inspectorate also cooperate with the Animal and Plant Health Agency under the Animal Health and Welfare (Scotland) Act 2006.

In Northern Ireland Aquaculture Production Business authorization is under the Aquatic Animal Health Regulations (Northern Ireland) 2009.

In Scotland the Alien and Locally Absent Species in Aquaculture (Scotland) Regulations make provision for the enforcement of Council Regulation (EC) No 708/2007 and for the notification of both an intended movement of an Annex IV species and the translocation of a locally absent species from within the UK. *Crassostrea gigas* (Pacific oyster) and *Oncorhynchus mykiss* (rainbow trout) are exempt.

In England those operating in the aquaculture sector must also abide by the Gangmasters (Licensing) Act 2004; a veterinary medicine mixing licence might be required (Veterinary Medicines Directive (EU Regulation (EC) No 183/2005 laying down requirements for feed hygiene); Transport authorization under Aquatic Animal health Regulations; Animal Transport Certificates under The Welfare of Animals (Transport) (England) Order 2006. Permissions to supply and introduce fish into inland waters (England and River Esk catchment area) Regulations 2015.

A Licence for collecting mussel seed from the Welsh Government is needed in Wales.

Marine Scotland authorize and inspect all fish farm businesses in Scotland for measures to contain fish and prevent escapes with sanctions available where non-compliance is identified (The Aquaculture & Fisheries (Scotland) Act 2013).

5) Leases and land-use rights

Lease or land use consent from The Crown Estate or other land owner is required in England, Scotland and Wales. Proof of site ownership or lease (land-based sites only) is required in Northern Ireland. Consent in principle, is required to the grant a seabed lease from the Crown Estate Commissioners or other owner of the seabed for use by marine sites.

An operator must apply to the Crown Estate for a lease for the right to occupy the site where the foreshore/seabed is owned by the Crown Estate (or the relevant landowner if foreshore or seabed is in alternative ownership). Planning permission is a prerequisite. New lease duration is generally 25 years.

Management tools for development of sustainable aquaculture

Over the UK there is intermittent use of tools for initial management of licensing and development of sustainable aquaculture, though these are being developed all the time.
Examples of use of online tools for decision-making and guidance can be obtained from Scotland.

Locational guidelines for marine finfish sites
These are produced each year by Marine Scotland and published (Scottish Government, 2019a). Here each marine water body have been assigned a max farmed fish biomass and given and environmental quality score (0 – 10) using a combination of "Nutrient Enhancement Index" and "Benthic Impact Index" (Gillibrand *et al.*, 2002). Using this score the water bodies are categorized on the basis of three categories;1) acceptable under extreme circumstances, 2) Prospects for

further fish farm development limited, 3) Areas of better prospects of satisfying environmental requirements.

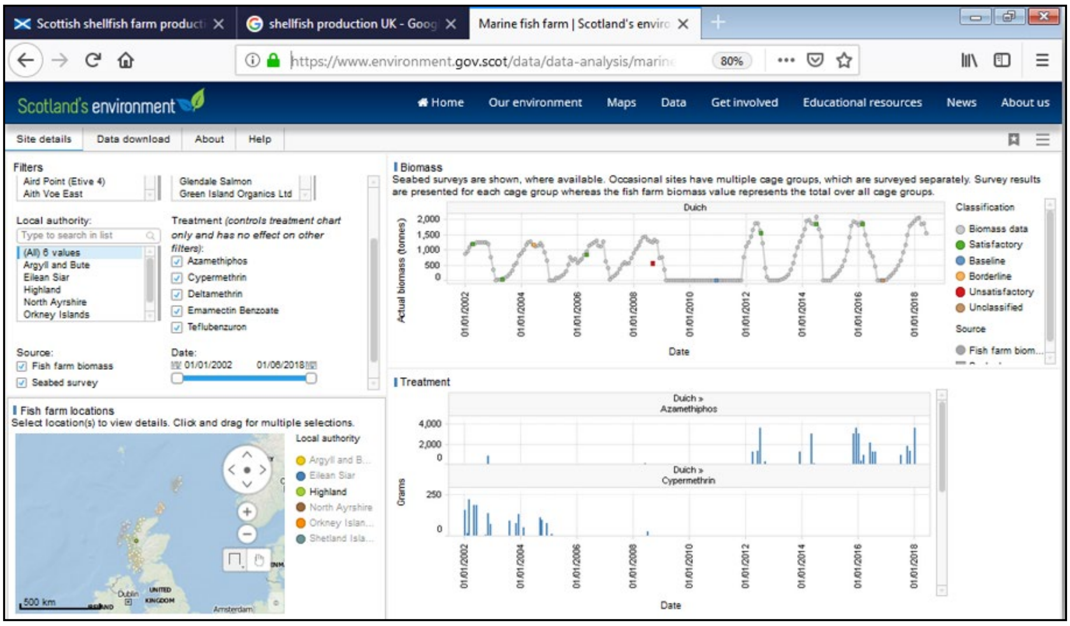

Figure 4. Scotland's Environment aquaculture site showing biomass and treatments for a fish farm site 2012 – 2018.

As part of the EIA statutory consultation with Marine Scotland during the planning permission application, the location of the potential development would be considered under these criteria, and action/advice given to the Local Planning Authority.

Production and licensing information for all fish and shellfish farms in Scotland are available using a combination of two websites: 1) Scotland's Environment aquaculture site (Scotland's Environment, 2019), and 2) Scotland's Aquaculture site (Scottish Government, 2019b). Both are GIS-based and have an easy to use graphic user interface, giving, see Figures 4 and 5.

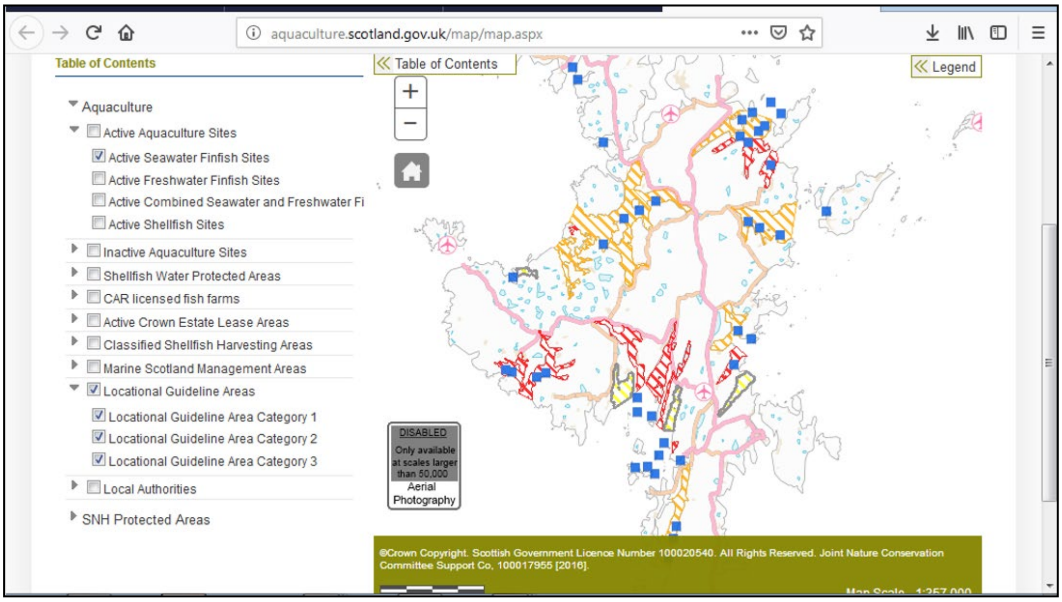

Figure 5. Scotland's Aquaculture Map showing the locational guidelines and active fish farm sites for Shetland.

Future developments

At present the future development of aquaculture production is limited in England, Wales and Northern Ireland and most expansion in seen to be in Scotland, and in particular for Atlantic salmon. There is a strategy, developed in 2016, to double production by 2030 to about 350,000 tonnes per year, bringing an estimated turnover of £3.6 billion and more than 9,000 new jobs (Scottish Government, 2019a). This will include the introduction of cutting-edge technologies to promote aquaculture in more dynamic environments and fish health. strategies.

Following a 22 months development, including a yearlong consultation process in 2017, and in response to two Scottish Parliamentary committees, SEPA has developed and is implementing a revised regulatory framework that will strengthen the protection of the marine environment (SEPA, 2019a). This has started with the marine net pen farms which is the largest part of the sector. This has developed a new licensing and environmental monitoring system (SEPA 2019b). This will provide a rigorous monitoring of the marine environment in the new more dynamic habitats being exploited by salmon net pen aquaculture.

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United States of America

U.S. Government Agency Abbreviations

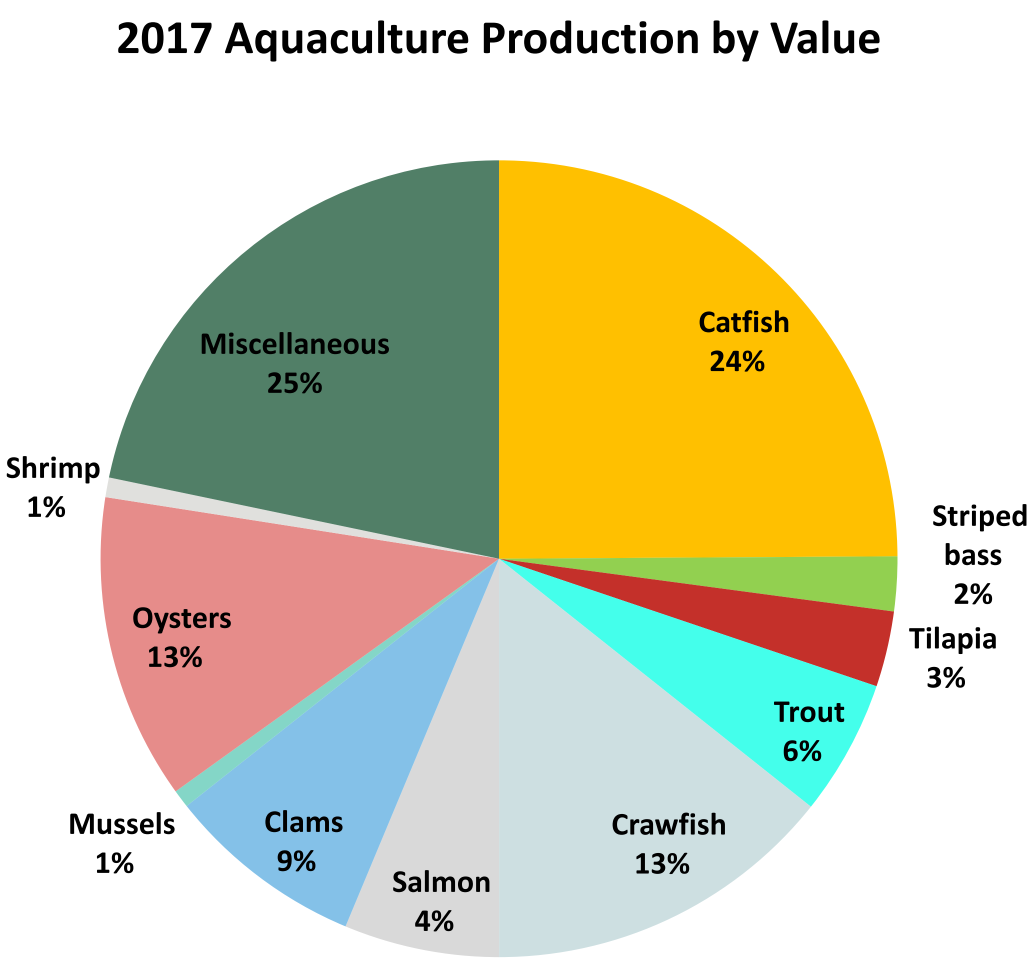
ACOE: Army Corps of Engineers
APHIS: Animal and Plant Health Inspection Service
ARS: Agricultural Research Service
DOC: Department of Commerce
DOI: Department of the Interior
EPA: Environmental Protection Agency
FDA: Food and Drug Administration
HHS: Department of Health and Human Services
NIFA: National Institute of Food and Agriculture
NOAA: National Oceanic and Atmospheric Administration
USDA: U.S. Department of Agriculture
USFWS: U.S. Fish and Wildlife Service

Freshwater and Marine Aquaculture Production Trends

The most recent year for which U.S. aquaculture production data are available is 2017. The U.S. remains a relatively minor producer of aquaculture, ranking 17th globally in aquaculture production. In 2017, total US marine and freshwater aquaculture production was 283,808 MT valued at $1.47 billion. Between 2014 and 2017, total US aquaculture production and value increased by 2.9% and 10.5%, respectively.
The US harvests far more wild-caught seafood than it produces from aquaculture. Aquaculture contributes only 6% of the volume of total US seafood production, however, aquaculture products yield 21% of the value because of focus on high-value marine food species.

The main species for aquaculture production in the US (listed in order of value) are catfish, crawfish, oysters, clams, trout, salmon, tilapia, striped bass, mussels, and shrimp. Other US production includes baitfish, ornamental/tropical fish, alligators, algae, aquatic plants, scallops, crabs, and marine and freshwater fish. Most of US aquaculture consists of freshwater species (87% by volume), including catfish, crawfish, and trout. Marine species make up a small proportion of aquaculture production by volume. However, marine species make up a disproportionately large part of the value of aquaculture in the US Shellfish, in particular, are produced in relatively smaller quantities but are high-value products. The US remains a large market for seafood, including aquaculture products. In 2018, the US imported more than 85% of its seafood, and it has been estimated that over half of US seafood imports are produced from aquaculture.

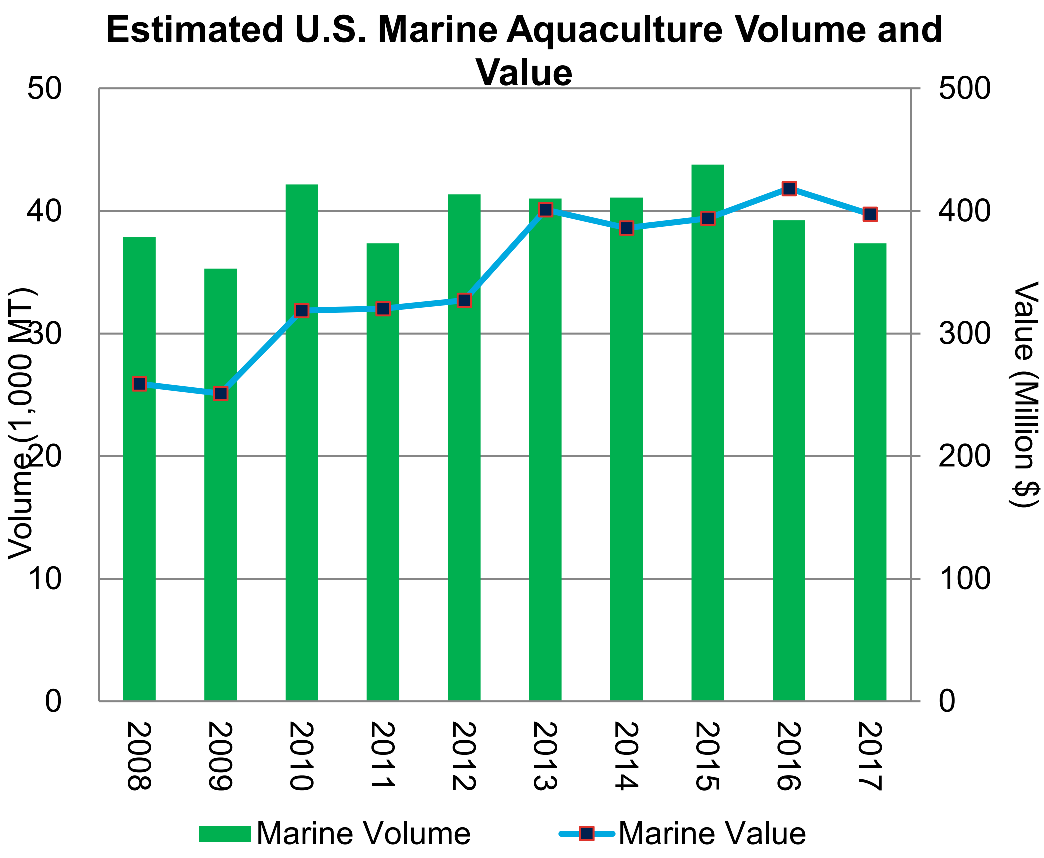
The US aquaculture industry is developing and is comprised of a diverse group of commercial companies that vary greatly in size and species cultured. Comprehensive collection of data remains a challenge and there is no consistent framework of reporting established. For example, Florida has a history of aquaculture production though lack of reporting and access to data has resulted in very limited data being included in this report. In addition, reporting of data are limited by state legislation such as Maine's confidentiality statutes that have prevented the release of Atlantic salmon production data since 2010. There's a clear need for improving the accuracy of US aquaculture data and NOAA's Office of Aquaculture has listed this as a specific goal in its five-year Marine Aquaculture Strategic Plan.



Marine Aquaculture[47]

In 2017, US marine aquaculture accounted for 37,347 MT of seafood valued at $397 M. Major US marine species are oysters (mainly *Crassostrea gigas* and *Crassotrea virginica*), clams (mainly hard clams *Mercinaria,* Manila clam *Venerupis philippinarum*, and geoduck *Panopea generosa*), Atlantic salmon (*Salmo salar*), mussels (mainly blue mussels, *Mytilus edulis*) and shrimp (mainly Pacific white shrimp, *Litopenaeus vannamei*).

[47] We define Marine Aquaculture in this section as marine and anadromous species cultured in the marine environment (e.g. oceans, bays, salt-water estuaries) and marine and anadromous species cultured on land facilities (e.g. recirculating systems)



Marine Aquaculture Legislation

Marine aquaculture is a small but increasingly important part of the missions of the Department of Commerce (DOC) and the National Oceanic and Atmospheric Administration (NOAA). The DOC sees aquaculture as a way to create jobs and economic activity. A federal agency under the DOC, NOAA sees aquaculture as a critical component to meeting increasing global and domestic demand for seafood and maintaining healthy ecosystems.

The Office of Aquaculture is within the National Marine Fisheries Service (NMFS) branch of NOAA. NMFS is involved in aquaculture from both science and policy perspectives: science to foster efficiency and sustainability; and policy to allow marine aquaculture while ensuring environmental responsibility. Marine aquaculture is a part of the NMFS mission by providing a growing amount of seafood to US consumers, supporting commercial and recreational fisheries, economic development and helping restore species and habitat.

Aquaculture is garnering increasing attention from DOC, members of Congress, and the private business sector for its ability to provide economic opportunities (especially in fishing communities) and potential to grow more seafood domestically in a safe, sustainable way. In 2011, NOAA and the DOC released complimentary Aquaculture Policies supporting domestic production of seafood, maintaining and restoring healthy marine ecosystems, and creating employment and business opportunities.

The 2011 DOC and NOAA Aquaculture Policies can be found at:
https://www.fisheries.noaa.gov/noaa-aquaculture-policies

In addition, in May 2016, NOAA NMFS announced release of its 5-year Marine Aquaculture Strategic Plan to guide all agency marine aquaculture activities from 2016 to 2020.

The NOAA NMFS Strategic Plan can be found at:
http://www.nmfs.noaa.gov/aquaculture/docs/aquaculture_docs/noaa_fisheries_marine_aquaculture_strategic_plan_fy_2016-2020.pdf

The U.S. Department of Commerce (DOC) released their 2018-2022 Strategic Plan. Developing domestic aquaculture was featured prominently and increasing US aquaculture production was included as a strategic objective and means to enhance job creation and improve our trade balance with other nations.

The DOC 2018-2022 Strategic Plan can be found at:
https://www.commerce.gov/sites/commerce.gov/files/us_department_of_commerce_2018-2022_strategic_plan.pdf

The Subcommittee on Aquaculture (SCA)

The Subcommittee on Aquaculture (SCA, formerly called the Interagency Working Group on Aquaculture, IWGA; and before that the Joint Subcommittee on Aquaculture, JSA) is an interagency group under the auspices of the Life Sciences Subcommittee of the National Science and Technology Council housed in the White House. The purpose of the SCA is to increase the overall effectiveness and productivity of federal aquaculture research, technology transfer, and technology assistance programs. Efficient, coordinated permitting processes will allow ocean industries, including commercial shellfish and finfish aquaculture, to save time and money and encourage economic growth without compromising federal agency responsibilities to protect health, safety, and the environment. Improved interagency coordination and less redundancy will reduce administrative waste and burden on federal agencies and reduce regulatory burden for industry.

Under the former IWGA, an Aquaculture Regulatory Task Force was created in 2013 under the auspices of the National Aquaculture Act of 1980. The regulatory task force aims to implement permitting efficiencies for marine aquaculture in consultation and partnership with the National Ocean Council and the IWGA. The task force consists of the following federal agencies: USDA: ARS, NIFA, and APHIS; DOC: NOAA; HHS: FDA; DOI: USFWS; EPA; and the ACOE. The task force also includes the following organizations in the Executive Office of the President: National Ocean Council; Office of Management and Budget; and Office of Science and Technology Policy.

More recently, in 2018 the SCA recharged the Regulatory Task Force and established a Research Task Force to coordinate updating the Federal Strategic Aquaculture Research Plan. In April, 2019, the Research Task Force published an outline of the National Strategic Plan for Federal Aquaculture Research 2020-2024 for public comment. Also, in October 2019, the Regulatory Task Force released for public comment the Draft Outline for a Work Plan for a Federal Aquaculture Regulatory Task Force to address aquaculture regulatory streamlining.

Federal Laws Governing Marine Aquaculture

Currently, the US has a complex regulatory structure for marine aquaculture, leading to an often convoluted and time-consuming permitting process. For example, the initial start-up of a commercial shellfish aquaculture farm in the US is subject to multiple regulatory requirements. In addition to an ACOE permit under the Rivers and Harbors Act (Section 10) and the Clean Water Act (Section 404), a commercial shellfish aquaculture farm must obtain all other required permits from the appropriate federal, state, local, and/or tribal authorities. Examples include leases and permits from state agencies and permits from other federal agencies under the Magnuson-Stevens Fishery Conservation and Management Act (for harvesting of some shellfish species in federal waters of the Exclusive Economic Zone); the National Marine Sanctuaries Act (for shellfish operations within a national marine sanctuary); Marine Mammal Protection Act (for shellfish aquaculture operations that may harm marine mammals); Migratory Bird Treaty Act (for shellfish aquaculture operations that may harm migratory birds); and other statutes.

<u>Federal Requirements Addressed by the ACOE Regulatory Program for Commercial Shellfish Aquaculture</u>**:**

The ACOE permit for commercial shellfish aquaculture directly addresses requirements under two federal laws:

- <u>Rivers and Harbors Act</u> – Section 10 of this law regulates activities and/or structures in, on, over, or under navigable waters of the US The ACOE permit authorizes activities, such as the installation of buoys, floats, racks, trays, nets, lines, tubes, containers, and other structures, in navigable waters of the US The primary focus is on the potential for these activities to interfere with other activities in navigable waters.

- <u>Clean Water Act (CWA)</u> – Section 404 of this law regulates discharges of dredged and/or fill material into waters of the US As it relates to aquaculture operations, the ACOE permit authorizes activities such as seeding, rearing, cultivating, transplanting, and harvesting. The primary focus is on the potential effects of these activities on the chemical, physical, and biological integrity of waters of the US

As part of the process for issuing a permit for commercial aquaculture under these two laws, the ACOE consults and coordinates with other federal agencies, coastal states, tribes, the public, and other parties as appropriate to meet additional legal requirements, including but not limited to the following:

- <u>National Environmental Policy Act (NEPA)</u> – This law may require the ACOE to prepare an environmental assessment or an environmental impact statement on the effects of aquaculture activities.

- <u>Treaties</u> – The ACOE is required to coordinate as necessary with federally recognized tribes to ensure aquaculture activities authorized under the permit do not impair reserved tribal rights. These rights include but are not limited to reserved water rights and treaty fishing and hunting rights.

- <u>Endangered Species Act (ESA)</u> – Section 7 of this law requires the ACOE to consult with NMFS and/or the USFWS, if a proposed federal action has the potential to adversely affect an ESA-listed species and/or the designated critical habitat for an ESA-listed species. The focus of these consultations is on the likelihood that the aquaculture activities authorized under the ACOE permit would jeopardize ESA-listed species or result in the destruction or adverse modification of their critical habitat.

- <u>Magnuson-Stevens Fishery Conservation and Management Act</u> – The Essential Fish Habitat (EFH) provisions of this law require the ACOE to consult with NMFS, if a proposed federal action has the potential to adversely affect the habitat of wild fish stocks managed by NMFS. The focus of these consultations is on the potential for activities authorized under the ACOE permit to adversely affect EFH. One example of EFH is submerged aquatic vegetation in nearshore areas where most US shellfish aquaculture production currently takes place.

- <u>Coastal Zone Management Act</u> – The federal consistency provisions of this law require state certification that the activities authorized by the ACOE permit comply with the enforceable policies of approved state coastal-zone management programs and that these activities will be conducted in a manner consistent with the program.

- Clean Water Act – Section 401 of this law requires state or tribal certification that the activities authorized by the ACOE permit comply with water quality standards.

- National Historic Preservation Act – Section 106 of this law requires the ACOE to consult with the State Historic Preservation Officer or Tribal Historic Preservation Officer, if the aquaculture activities authorized by the permit may affect historic properties or areas of historic or cultural significance.

- Fish and Wildlife Coordination Act – This law requires the ACOE to consult with USFWS, NMFS, and appropriate state agencies, if the aquaculture activities authorized by the permit would modify a body of water in ways that could harm fish and wildlife resources.

- National Marine Sanctuaries Act – Section 304(d) of this law requires the ACOE to consult with the National Marine Sanctuary Program, if the aquaculture activities authorized by the permit are likely to destroy or injure any sanctuary resource (for Stellwagen Bank National Marine Sanctuary, such consultations are required for action that "may affect" that sanctuary, which is a lower threshold).

Latest Topics in Marine Aquaculture

U.S. Commerce Committee Hearing on Offshore Aquaculture

On October 16, 2019, US Senator Roger Wicker, Chair of the Senate Committee on Commerce, Science, and Transportation, convened a hearing titled "Feeding America: Making Sustainable Offshore Aquaculture a Reality."

https://www.commerce.senate.gov/2019/10/improving-security-at-america-s-airports-stakeholder-perspectives

Witnesses representing different aquaculture stakeholder groups attended the hearing, provided testimony and answered questions from Senators. One of the witnesses was Paul Doremus, NOAA's Deputy Assistant Administrator for Operations, National Marine Fisheries Service, and his testimony is provided at the following link:

https://www.commerce.senate.gov/services/files/861F4A64-03AA-46DB-9E3D-F70DEE29B2DE

This hearing examined opportunities and barriers to expanding sustainable aquaculture in the US The witnesses discussed the environmental, economic, and social realities of open ocean aquaculture, and the need for a streamlined and predictable policy framework for advancing the development of offshore aquaculture.

The Advancing the Quality and Understanding of American Aquaculture Act (AQUAA)

On June 26, 2018, US Senator, Roger Wicker (Republican – Mississippi) introduced the Advancing the Quality and Understanding of American Aquaculture (AQUAA) Act in the Senate. US Representatives, Steven Palazzo and Colin Peterson introduced a companion piece of the same bill to the House on September 28, 2018. The AQUAA Act would streamline the permitting process for aquaculture farms in federal waters, fund research and development to advance the aquaculture industry, and give the National Oceanic and Atmospheric Administration (NOAA) regulatory authority over fish farming in federal waters. The Act would establish a twenty-five-year permit to be issued by NOAA aiming to give individuals the security of tenure necessary to secure financing for aquaculture operations. In addition, the Act would direct the Secretary of Commerce to initiate and lead programmatic environmental impact statements (EISs) in certain areas of the exclusive economic zone (EEZ). The bill explicitly notes that Congress should prioritize directing funds towards this program over all others.

On March 11, 2020, the AQUAA was reintroduced by US Representatives, Colin Peterson and Steven Palazzo.

The AQUAA Act can be found at:
https://www.congress.gov/115/bills/s3138/BILLS-115s3138is.xml

NOAA Marine Aquaculture Research

NOAA continues to refine culture methods for key existing and emerging aquaculture species around the country. Research efforts include:

- NMFS Northwest Fisheries Science Center: sablefish (*Anoplopomo fimbria*), Olympia oyster (*Ostrea conchaphila*), and seaweeds
- NMFS Southwest Fisheries Science Center: California yellowtail (*Seriola dorsalis*) and abalone (*Haliotis* spp.)
- NMFS Northeast Fisheries Science Center: eastern oyster (*Crassostrea virginica*), Mussels (*Mytilus edulis*) and microalgae for shellfish hatcheries.
- National Ocean Service (NOS) National Centers for Coastal Ocean Sciences (NCCOS) Beaufort Laboratory: red porgy (*Pagrus pagrus*) and grey triggerfish (*Balistes capriscus*)

Key Examples of research:

NOAA has identified sablefish as a candidate species for the Pacific Northwest due to market characteristics, such as a high price-point, white flesh, and limited production from wild harvest. Scientists at the NMFS Northwest Fisheries Science Center have made significant advancements in the aquaculture technologies for sablefish in the last several years, having investigated key research topics, including the effects of temperature; viability of using all female sablefish; effectiveness of hormonal treatments, sterilization, and immersion vaccination; and optimizing tank design, environmental conditions, and feeds composition. NOAA is working to build partnerships with the interested private sector and tribal parties to transfer sablefish farming technology. One Pacific Northwest tribal group and several private sector partners are interested in farming this species, if financial and permitting barriers can be overcome.

Scientists at the NMFS Southwest Fisheries Science Center have continued to advance aquaculture technologies for California yellowtail, a species with high potential for commercial culture in the US Scientists have undertaken several genetic and genomics projects for this species that aim to improve production efficiency in commercial operations, as well as evaluate effects of proposed commercial operations on wild stocks. NOAA has partnered with California Sea Grant and Hubbs-SeaWorld Research Institute to develop new land-based tank technologies to improve larval rearing. NOAA scientists and partners may have an opportunity to transfer these technologies to the private sector through a commercial cage farm that would be located in the Southern California Bight. The farm is working on permitting.

Developing Tools for Managing Marine Aquaculture

NOAA has continued to develop synthesis documents and refine tools for managers around the country. This work is primarily completed at NOAA's National Ocean Service (NOS) National Centers for Coastal Ocean Science (NCCOS) at the Beaufort, North Carolina Laboratory. Research efforts include:

- In April, 2019, NOAA and the Department of Interior's Bureau of Ocean Energy Management released Ocean Reports (https://coast.noaa.gov/digitalcoast/tools/ort.html). This web-based, report-centric tool provides coastal and ocean planners with a high-level analysis for their custom-drawn area of interest. It provides summary statistics and infographics for six main topics: general information, energy and minerals, natural resources and conservation, oceanographic and biophysical, transportation and infrastructure, and economics and commerce.

- In February, 2018, NOS released the web-mapping application called Gulf AquaMapper that is designed to assist managers in identifying suitable areas for aquaculture development in the Gulf of Mexico. The application provides high resolution maps to improve the coordination and transparency of permits and siting, which in turn reduce planning costs on industry and regulatory agencies and allow for more investment opportunities in domestic seafood production. This approach is expanding to other regions of the US
- NOS NCCOS has also completed testing and refinement of models for benthic and water column nutrient impacts, Best Management Practices (BMP) for offshore marine fish culture, ecological management of shellfish farms (FARM model), habitat value of shellfish farms (HIA), and viewscape issues (CanVis) posed by marine aquaculture.

Annex 4: Overview of laws and regulatory standards for monitoring and managing environmental impacts of marine finfish aquaculture in countries contributed to WGEIA

Issue	Sub-issue	Description
Effluents	Fishmeal/fish oil use/replacements	The feed industry is sourcing ingredients globally. Due to many factors (e.g. policies, climate) these ingredients can come with safety concerns. Contaminants in feeds can effect fish welfare and be transferred to the edible part of the fish, hence posing a risk for human health.
	Biodeposits under cages: Organic loading	organic enrichment in the form of biological and geochemical changes. Extremely enrichment conditions often result directly beneath the cages and grade progressively to natural conditions within 200-1000m from the farm. Spatial extent and severity of effects are highly site-specific. Discharges can also include contaminants in the form of therapeutants. (zinc, antibiotics, other medicines)
	Contaminants (Antifouling etc)	Different chemicals are used in open-cage aquaculture production, as copper as antifouling agent. These chemicals can be accumulated in the sediment and have negative impact on the ecosystem
	Residues of medicine/drugs (Antibiotics, pesticides)	Medicines are prescribed and used in fish farms to control pathogens (especially bacteria and parasites), but spread of residues can also have negative impact on wild non-target species
	Effects on sensitive habitat	Tolerance limits of sensitive habitats exposed to fish farm waste and such knowledge on safe distance to farms.
	Water column impacts : Nutrification	Fish excretion releases large quantities of nutrients (ammonia, nitrates) to the water column which can result in eutrophication. Phytoplankton blooms can be stimulated and can result in a change in trophic state. Concern mainly revolves around potential for blooms to harmful algal species, which can be toxic to humans, marine life and cause closures of shellfish harvesting operations. Norwegian waters are largely oligotrophic and the addition of nutrients is not perceived to be a negative issue. Studies to date on the effects on concentrations a short distance from the farm or on the growth and productivity of macroalgae have suggested that the potential for effects is negligible.
Pathogens/parasite transfer	Virus & bacteria	Viral and viral diseases can be spread from farmed fish and cause mortality on different species of wild fish
	Parasites	Spread of parasites is one of the main challenges in open cage aquaculture, e.g spread of salmon lice from Atlantic salmon farming causing mortality on wild salmonids.
Genetic and ecological issues	Escapes	Escape of domesticated fish into wild populations, and their subsequent spawning and introgression, represents a threat to the genetic integrity, productivity and long-term viability of wild populations.
	Effects on wild species	Impacts on the surrounding ecosystem (e.g. distribution and use of spawning areas for wild fish, impacts on marine mammals and birds)

Finfish	**Issue** **Sub-issue** **Description of the sub-issue**	Effluents Fishmeal/fish oil use/replacements The feed industry is sourcing ingredients globally. Due to many factors (e.g. policies, climate) these ingredients can come with safety concerns. Contaminants in feeds can effect fish welfare and be transferred to the edible part of the fish, hence posing a risk for human health.			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Canadian Food Inspection Agency	Feeds Act			
Denmark	Ministry of Environment and Food for fish farms in locations more than 1 nm from the coast, and also local municipalities for fish farms under 1 nm from the coast.	Legal Act for Environmental Protection No. 966 af 23.06.2017, and Order for Environmental Permissions No. 1317 af 20.11.2018 and Guideline for seacage farming No. 9163 af 31.03.2006.		Developments in more sustainable feed compared to the use of sustainable ingredients and minimization of environmental impacts are taking place all the time.	Ongoing research
Faroe Islands	Faroese Food and Veterinary Authority	Residues Directive (Directive 96/23/EC)	In accordance with the directive	Development of feed towards more effective feed conversion ratio	Use of next generation proteins (seaweed + insect meal)
Germany	Various (Federal/statal)	Animal welfare law, Feed regulation, Water law			Suitable doses of antioxidants, fate of antioxidants in fish and environment
Ireland	Department of Agriculture Food and Marine (DAFM) - Implements the overall residues controls in Ireland; Food Safety Authority of Ireland (FSAI) - Coordinates the activities of the departments and agencies involved; Sea Fisheries Protection Authority (SFPA) - Responsible for ensuring compliance with the Directive for finfish aquaculture; Marine Institute - Implements the surveillance monitoring programme for farmed fish on behalf of SFPA and is the official laboratory for residue sampling and analysis; DAFM Veterinary Inspectors - Carries out routine on-farm inspections to verify compliance with various regulations - including fish health, animal remedies, feedstuffs, etc.	Residues Directive (Directive 96/23/EC), National Animal Remedies Act, 1993 and National Residues Control Plan-NRCP for the monitoring of certain chemical substances and residues in a range of food producing species and products e.g. cattle, pigs, sheep, farmed finfish.	In accordance with this directive, salmon and trout from fish farms are routinely monitored for the presence of veterinary residues, contaminants and other substances. The purpose is to support consumer protection (food safety), ensure proper use of medicines (e.g. adherence to withdrawal periods), and control use of illegal substances. This legislation and monitoring does not deal with broader environmental issues that may be associated with use of treatments. The sampling strategy depends on the substance. Primarily fish are sampled at harvest to ensure that levels of authorised medicines do not exceed Maximum Residue Levels (MRLs).	In the event of non-compliance, follow-up actions may include additional investigations including unannounced visits to determine the cause and extent of non-compliance and may result in prosecution.	The longterm fate and persistence of chemotheraputents in marine systems (and in particular sediments). Also, analysis sensitivity for testing for compounds e.g., emamectin in sediments.
Norway	Fish feed ingredients and fish feed from the feed industry are analysed yearly to identify undesirables. Feed ingredients and feed for farmed fish are checked for residues of legal pharmaceuticals, environmental contaminants, additives and heavy metals. In addition, a proportion of the samples is studied for illegal pharmaceuticals and feed ingredients. The farmed fish fillets are also studied for undesirable substances. This monitoring is carried out on assignment for the Norwegian Food Safety Authority. Fish feed ingredients and fish feed from the feed industry are analysed yearly to identify undesirables. Feed ingredients and feed for farmed fish are checked for residues of legal pharmaceuticals, environmental contaminants, additives and heavy metals. In addition, a proportion of the samples is studied for illegal pharmaceuticals and feed ingredients. The farmed fish fillets are also studied for undesirable substances. This monitoring is carried out on assignment for the Norwegian Food Safety Authority.	Regulation (EC) No 882/2004 of the European Parliament and of the Council of 29 April 2004 on official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules is the legal framework for sampling methods and methods of analysis of feed for control purposes. Commission Regulation (EC) No 152/2009 of 27 January 2009 laying down the methods of sampling and analysis for the official control of feed establishes the sampling method and the methods of analysis of feed for control purposes. Commission Regulation (EU) 2017/771 of 3 May 2017 amending Regulation (EC) No 152/2009 as regards the methods for the determination of the levels of dioxins and polychlorinated biphenyls updates the analytical requirements for the analysis of dioxins and polychlorinated biphenyls. In this Regulation reference is made to the Guidance Document on the Estimation of LOD and LOQ for Measurements in the Field of Contaminants in Feed and Food and a Guidance Document on Measurement Uncertainty for Laboratories performing PCDD/F and PCB Analysis using Isotope Dilution Mass Spectrometry which have been elaborated by the European Reference Laboratories in the field of contaminants in feed and food. In 2013, the sampling procedure has been completely updated by Commission Regulation (EU) No 691/2013 amending Regulation (EC) No 152/2009 as regards methods of sampling and analysis A guidance documentSearch for available translations of the preceding for the implementation of Commission Regulation (EU) No 691/2013 has been elaborated and has been endorsed by the Standing Committee on the Food Chain and Animal Health – section Animal Nutrition.	The Norwegian Food Safety Authority (Mattilsynet) is collecting feed and feed ingredient samples in Norway. These are around 80 feed samples, 10 fishmeal, 10 vegetable meal, 10 fish oil, 10 plant oil, 8 mineral premix and 8 vitamin premix per year. Samples are send to the Institute of Marine Research for analysis with accredited methods. Analysis include: microbiological analysis (e.g. salmonella, enterobacteriacea), mycotoxins, heavy metals, organic contaminants (e.g. dioxins, PCBs, PAHs), pesticides (e.g. chlorinated), brominated flame retardants, fatty acids, minerals, synthetic antioxidants (e.g. ethoxyquin, BHT, BHA) and vitamins.	Feed withdrawal	Unknown compounds, e.g. new pesticides, residues, mycotoxins, etc.
Portugal	DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt)	Regulation (EC) nº 882/2004 of the European Parliament and of the Council - Establishes official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules DL 193/2007 - transposes into Portuguese law Directive 2002/32/EC of the European Parliament on undesirable substances in animal feed and subsequent alterations to Annex I and II	Manufacturers must report to the Veterinary authorities (DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt) on a yearly-basis: Manufacturers of additives, premixtures and compound feedstuffs, as well as producers of derivatives and by-products, must report to DGAV the following details of their annual manufacture: - Additives: The name, trademark and quantities of additives manufactured; - Premixes: The quantities of additives used and premixes of additives manufactured, broken down by composition, trade mark and target animal species; - Compound feedstuffs: The quantities of additives used, the quantities of premixtures of additives used and their composition, and the quantity of compound feedingstuffs made by breaking down the trademark and animal species of destination; - Derivatives and By-products: Their designation and quantities of derivatives and by-products produced. on a monthly-basis: Manufacturers of raw materials made from processed animal protein or animal fat and manufacturers of premixtures or compound feedingstuffs should complement the yearly communication to the DGAV with: - Raw Material Manufacturers: (i) daily recording of quantities manufactured; (ii) quantities put into circulation; (iii) recipients and their packing slip numbers and invoices. Manufacturers of premixtures or compound feedstuffs incorporating raw materials consisting of processed animal protein or animal fat: (i) daily recording of quantities purchased; (ii) Document number confirming the purchase, and its use by type of premix or compound feed manufactured.		Use of alternative ingredients (e.g. plant and insect meal) and additives (glycerol, algae extracts, n-3 oils pre- and pro-biotics)
UK (Scotland)	Food Standards Agency	Feed law in the UK, follows EC Regulation and Directives. In Scotland, regulation is enforced by The Feed (Hygiene and Enforcement) Scotland Regulations 2005. There are also codes of good practice and quality assurance schemes.	In accordance with the directives, regulations and schemes.		
USA	Food and Drug Administration	Food Safety Modernization Act (FSMA; https://www.fda.gov/food/guidance-regulation-food-and-dietary-supplements/food-safety-modernization-act-fsma) issued 7 major rules to implement FSMA of which the following have to do with animal feed: - Current Good Manufacturing Practice and Hazard Analysis and Risk-Based Preventive Controls for Food for Animals (CGMP) - Foreign Supplier Verification Programs (FSVP) for Importers of Food for Humans and Animals - Sanitary Transportation for Human and Animal Food	FSVP requires that imported feed has been produced in a manner that meets applicable U.S. safety standards (see: https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-foreign-supplier-verification-programs-fsvp-importers-food-humans-and-animals).		
China	The Ministry of Agriculture and Rural Affairs is responsible for the national supervision and management of feed and feed additives The fisheries governance authorities and agriculture administrations of the local people's government at or above the county level is responsible for the management of feed and feed additives in its administrative region	- Regulations on Feed and Feed Additives (2012) - Fisheries Law of China (2004) Article 19 Noxious and harmful bait and feed are prohibited in aquacultural production.	Article 31 The administrative department of agriculture under the State Council and the feed management department of the people's governments of provinces, autonomous regions and municipalities directly under the Central Government shall monitor the quality and safety of feed and feed additives throughout the country or their administrative regions in accordance with their duties and responsibilities, and issue feeds and feeds additive quality and safety warning information based-on the monitoring results.	Article 34 The administrative department of agriculture under the State Council and the feed administration department of the local people's government at or above the county level may take the following measures during supervision and inspection: (1) Carry out on-site inspection of the production, operation and use places of feed and feed additives; (2) Checking and copying relevant contracts, bills, account books and other related materials; (3) Seizure of feed materials, feeds, feed additives, pharmaceutical feed additives, additive premixed feeds used for illegal production of feed, raw materials used for illegal production of feed additives, and illegal production of feed and feed additives; seizure of tools, facilities for illegally producing feed and feed additives; (4) Seal off the places that illegally produce and operate feed and feed additives.	

Finfish	**Issue**	Effluents			
	Sub-issue	Biodeposits under cages: Organic loading			
	Description of the sub-issue	Biodeposits from fish farms, primarily in the form of fish faeces, causes severe benthic organic enrichment in the form of biological and geochemical changes. Extremely enrichment conditions often result directly beneath the cages and grade progressively to natural conditions within 200-1000m from the			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	The federal Department of Fisheries and Oceans (DFO) is the principal regulator of the deposition of deleterious substances although how it is managed varies across provinces and territories.	Organic loading from marine finfish operations is regulated under the Aquaculture Activities Regulations according to the associated Aquaculture Monitoring Standard, and provincial legislation and regulations	https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-ann7-eng.htm Aquaculture Activities Regulations: 10 (1) In the case of an aquaculture facility that is located over a soft bottom and cultivates finfish in tidal waters in or adjacent to Quebec, Nova Scotia, New Brunswick, British Columbia, Prince Edward Island or Newfoundland and Labrador, the owner or operator of the facility (a) must take samples of the benthic substrate in the manner and at the times and locations specified in the Monitoring Standard and determine the concentration of free sulphide in the samples in accordance with that Standard; (b) must take additional samples of the benthic substrate, in the manner and at the times and locations specified in the Monitoring Standard, if (i) in the case of a facility located in tidal waters in or adjacent to Quebec, Nova Scotia, New Brunswick, Prince Edward Island or Newfoundland and Labrador, the mean concentration of free sulphide as calculated at the locations specified in the Monitoring Standard exceeds 3000 μM, and (ii) in the case of a facility located in tidal waters in or adjacent to British Columbia, the mean concentration of free sulphide as calculated at 30 m and 125 m from the structure that contains the cultivated fish exceeds 1300 μM and 700 μM, respectively; and (c) must not restock the facility if the concentrations of free sulphide exceed the applicable concentration limits set out in paragraph (b). Marginal note:Visual monitoring instead of sampling (2) The owner or operator of an aquaculture facility must conduct visual monitoring in accordance with section 11 instead of the sampling described in subsection (1) if the owner or the operator cannot obtain, from each of the locations specified in the Monitoring Standard, benthic substrate samples that (a) contain substrate to a depth of at least 5 cm; and (b) have a volume of at least 15 ml and undisturbed sediment-water interface. Marginal note:Visual mon toring of substrate 11 (1) This section applies to aquaculture facilities that cultivate finfish in the waters referred to in subsection 10(1) but (a) are not located over a soft bottom; or (b) are located over a soft bottom in respect of which subsection 10(2) applies. Marginal note: Monitoring and restocking (2) The owner or operator of a facility referred to in subsection (1) (a) must conduct visual monitoring of the benthic substrate in the manner and at the times and locations specified in the Monitoring Standard; (b) must not, if the facility is located in tidal waters in or adjacent to Quebec, Nova Scotia, New Brunswick, Prince Edward Island or Newfoundland and Labrador, restock the facility if the visual monitoring shows the presence of Beggiatoa species or similar bacteria, marine worms or barren substrate in more than 70% of the locations specified in the Monitoring Standard; and (c) must not, if the facility is located in tidal waters in or adjacent to British Columbia, restock the facility if visual monitoring shows that Beggiatoa species or similar bacteria or marine worms cover (i) 10% or more of any four segments of substrate specified in the Monitoring Standard that are within 100 m to 124 m from the fish containment structure, or	Aquaculture Activities Regulations s7(2): In the case of an aquaculture facility that cultivates finfish and that is operated under an aquaculture licence that permits a standing biomass of more than 2.5 t or an annual production of more than 5 t, the owner or operator of the facility must take reasonable measures to minimize the deposit of fish feces and unconsumed feed, having regard to the factors set out in paragraphs (1)(a) to (c). Aquaculture Activities Regulations 10(1)(c): must not restock the facility if the concentrations of free sulphide exceed the appliable concentration limits set out in paragraph (b)	Validation of new methods for measuring organic enrichment impacts, either directly (biological) or using proxies (chemical or remote methods), determination of thresholds that are equivalent to existing regulatory thresholds. Monitoring off-lease has recently begun which will add to the understanding of the scale and persistence at the far-field Fate (and outcome) of organic loading at the ecosystem level poorly known
Denmark	Ministry of Environment and Food for fish farms located more than 1 nm from the coast, and local municipalities for fish farms under 1 nm from the coast.	Legal Act for Environmental Protection No. 966 af 23.06.2017, and Order for Environmental Permissions No. 1317 af 20.11.2018 and Guideline for seacage farming No. 9163 af 31.03.2006. Legal Act for international nature protection No. 119 26.01.2017	Hydrodynamic model analyses and sediment samples and analyses. Sediment samples for e.g. redox, N, P, BOD under the nets, up- and downstreams, reference points and other relevant points. Monitoring requirement is dependent on the size and the placement of the fishfarm. Samples and analyses: by independent 3. party firm.	Spacial planning,	
Faroe Islands	Environment Agency www.us.fo	Legal Act for Environmental Protection No. 134 af 28.10.1988, and Guideline for Environmental monitoring of Fish farm No. 19/2018	Seabed monitoring at all active sites at maximum biomass as a minimum. Thresholds are set for the allowed impact, in form of Ph and redox potential and the appearance of the seabed, and also for organic carbon content, zinc and copper.	Intensified surveys, spatial planning, biomass regulation	Monitoring of macrofauna is based on conditions in other countries. Monitoring needs to be benchmarked in the local environment.
Germany	Coastal Zone: State Agencies; EEZ: BSH (Federal Office of Navigation and Hydrography)	EU-Regulations, Federal and state laws on environmental protection		Stocking density, Feed quality, Site selection	
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of finfish aquaculture in Ireland; The Marine Institute is responsible for reviewing annual benthic reports from fish farm sites and reporting to DAFM.	Monitoring set out under Licence conditions - Fisheries (amendment) Act 1997:	Seabed monitoring is carried out at all active sites on an annual basis according to the Monitoring Protocol No.1 for Offshore Finfish Farms Benthic Monitoring (subject to revision from time to time) - Revised December, 2008: (https://www.agriculture.gov.ie/seafood/aquacultureforeshoremanagement/marinefinfishprotocols/)	Resurvey, stocking and feed control.	Real time data lacking - benthic reports are reviewed up to 1 year after surveys are completed. Therefore, reaction to negative results are delayed and problematic. No standards for hard-substrate seafloor.
Norway	Norwegian Directorate of Fisheries (NDF) and Norwegian Environment Agency	The Aquaculture Act. Specifies Purpose (§1), Environmental Standards (§10), requirement for Environmental monitoring (§11). Provides motivation for B- and C- Investigations (Standard: NS 9410:2016). Regulation pursuant to the Act including Aquaculture Operations (together with Food Safety Act.).	Environmental monitoring is conducted both under and close to the farm (the local impact zone) and away from the farm (intermediate impact zone). Benthic impact (indicators) are used to initiate a range of management responses (NS9410:2016). B-investigations target the local zone and utilize a pH/Eh index and a range of sensory parameters, while C-investigations are conducted (less frequently) to assess the outer zone of effect using more detailed benthic indicators (including macrofauna). There are established thresholds for different impact levels (4) associated with increasingly severe management responses (frequency of sampling) employed in response to increases in environmental impacts. If the level of impact exceeds level 3 the authorities decide on mitigating actions. There is also a stipulation that sites must be fallowed for a period of at least two months after harvest. Hardbottom monitoring: Has until now been performed as an alternative survey at the requirement of the authorities. In 2018 some basic guidance was provided on how to conduct hard bottom monitoring, which revolves around standardising the quality, type and number of images collected. Hardbottom EQS are still under development. Modelling: Enrichment footprints can be predicted from depositional models. Norway has several depositional dispersal models under development that can be used to predict waste distribution and ecological effects footprint. Other 'off-the-shelf' models exist such as NEW-DEPOMOD. Baseline information: detailed baseline surveys now required prior to introducing a new farm. Long-term regional monitoring occurs in some regions. Otherwise, the authorities determine where and when to perform regional monitoring. Benthic fauna and other chemical parameters are measured annually at a few stations along the Norwegian coastline as part of a long-term monitoring strategy (ØKOKYST: http://www.miljodirektoratet.no/no/Tema/Miljoovervakning/Naturovervaking/Hav-og-kyst/Okoystemovervaking-i-kystvann/). Results are considered in the context of the European Water Directive Framework (WDF) guidelines. Also, the recent (2017) BluePlanet initiative (https://www.blueplanet.no/baerekraftig-havbruk) has more detailed monitoring programs in three southern regions.	Control of feeding levels / biomass. Fallowing. Farm positioning / repositioning. Undertake good, high-resolution depositional modelling to predict extent of footprint. Closed containment farms (not yet in commercial use).	Effect on non-soft-sediment benthic habitats (and species) not well understood. No standardized monitoring system for hard-bottom habitats. Regional / far-field effects are not well understood and difficult to regulate. Lack of historical long-term regional data and poor comprehension of what constitutes pristine baseline conditions.
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt)	DL226-A/2007, altered by DL391-A/2007, DL93/2008, DL107/2009, DL245/2009, DL82/2010, and L44/2012 Establishes the framework for the use of water resources DL38/2015 Develops L17/2014 which establishes the Bases of the Planning and Management Policy of the National Maritime Space, defining among other: b) legal framework applicable to titles of private use of the national maritime space (TUPEM); d) system for permanent monitoring and technical evaluation of the planning of the national maritime space; and e) system of private use of water resources in transitional waters for aquaculture purposes. L58/2005, altered by DL245/2009, DL26/2010, and DL130/2012 Approves the Water Law, transposing into Portuguese law the Directive 2000/60/EC of the European Parliament and of the Council and laying down the foundations and institutional framework for sustainable water management DL77/2006 Complements the transposition to Directive 2000/60/EC of the European Parliament and of the Council P276/2017 Establishes the arrangements and amount of the security deposit needed to ensure good ecological condition the environment and water bodies as well as the	DL236/98, altered by DL52/99, DL53/99, DL54/99, DL56/99, DL431/99, DL306/2007, and DL135/2009 Establishes quality standards, criteria and objectives with the purpose of protecting the aquatic environment and improving the quality of the water in relation to its main uses. DL103/2010, altered by DL83/2011, and DL218/2015 Transposes into Portuguese law Directive 2008/105/EC European Parliament and of the Council, on environmental quality standards in the field of water policy, and partially transposes into Portuguese law Directive 2009/90/EC, of the European Parliament and of the Council, on the technical specifications for chemical analysis and monitoring of water status. Specific requirements can be included into the Environmental impact assessment (case-by-case basis) DL151-B/2013, altered by DL47/2014 and DL179/2015 - Legal framework for the assessment of the environmental impact of public and private projects (transposing into Portuguese law the Directive 2011/92/EU) P395/2015 - Establishes the formal technical requirements to be followed by the procedures provided for in the legal regime for environmental impact assessment	P368/2015 - Establishes fees to be charged by the authorities under the environmental impact assessment procedure P276/2017 - Establishes the arrangements and amount of the security deposit needed to ensure good ecological condition the environment and water bodies as well as the removal of any infrastructure at the end of the licensing	Lack of "control" ((unaltered/pristine/baseline) environment for the establishment of "good" status no follow-up / continuous monitoring of discharges and consequent modelling
UK					

USA	Environmental Protection Agency (EPA) or states authorized by EPA	Clean Water Act - Section 402 establishes the National Pollutant Discharge Elimination System (NPDES) and authorizes EPA (or states authorized by EPA) to issue permits for point source discharges of pollutants into waters of the United States. Effluent Limitation Guidelines are established for Concentrated Aquatic Animal Production facilities, including marine net pen aquaculture producing 100,000 pounds or more of aquatic animals per year (40 CFR Part 451). More information can be found at: https://www.epa.gov/eg/concentrated-aquaticanimal-production-effluent-guidelines; http://www.ecfr.gov/cgi-bin/text-idx?SID=b32f065c3e56d423dbc1858e2a077818&mc=true&node=pt40.32.451&rgn=div5#sp40.32.451.b	Commercial fish farming occur primarily in the states of Maine and Washington and both these states are authorized by EPA to issue NPDES permits. Benthic monitoring requirements for these two states include: Maine - the Department of Environmental Protection (DEP) requires monitoring of sulphide at 35 meters a minimum of once per growing cycle. If sulphide is above a set level, monitoring for benthic infauna is required when maximum biomass for the facility occurs. Regarding drug use for disease control, the DEP may require sediment monitoring for a specific drug or metabolite if data or literature is not available. A monthly drug use report is required. Washington - the Department of Ecology (ECOLOGY) manages Section 402 NPDES permits that require sediment monitoring of benthic impacts around a 100-foot perimeter from the farm sites. Impact limits are set for the organic enrichment of sediments to distinct threshold values. The Section 402 NPDES permit requires that a sampling plan complying with specific permit requirements be developed, including a sediment monitoring cycle to be carried out by a third-party consultant.	Washington - Mandatory mitigation and monitoring is required if sediment standards exceed the limits and closure monitoring is required of any station that exceeds the threshold limits until sediment quality is returned to allowable levels.	
China	Fisheries governance authorities at all levels	Fisheries Law of China (2004) Article 20 Aquacultural operators shall protect the ecological environment of the waters by scientifically defining the density of aquaculture, and through rational feeding and rational application of fertilizer and use of medicines, and contamination of the waters therefrom is not allowed. Law of the People's Republic of China on the Prevention and Control of Water Pollution (2017) Article 57 Aquaculture activities should protect the ecological environment of the waters, scientifically determine the culture density, reasonably feed and use drugs to prevent pollution of the water environment.	Fisheries Law of China (2004) Article 36: People's governments at all levels shall take measures to protect and improve the ecological environment of fishery waters and prevent pollution. The ecological environment of fishery waters shall be supervised and regulated, and fishery pollution shall be investigated and handled in accordance with the relevant provisions of the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. Some research projects include benthic survey of aquaculture sites.	Fisheries Law of China (2004) Article 47: Anyone who damages the ecological environment of the fishery waters or causes fishery pollution shall be investigated for legal liability in accordance with the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. Aquaculture spatial planning; Appropriate siting and culture density.	There is still a significant lack of knowledge on impact of bio-deposits

Finfish	**Issue**	Effluents
	Sub-issue	Contaminants (Antifouling etc)
	Description of the sub-issue	Different chemicals are used in open-cage aquaculture production, as copper as antifouling agent. These chemicals can be accumulated in the sediment and have negative impact on the ecosystem

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, provincial government	Fisheries Act, provincial regulations	Environmental monitoring at the far-field (off-lease) at selected sites is conducted by Fisheries and Oceans Canada (see Aquaculture Monitoring Program)		Fate and persistence of active ingredients and derivates in environment; effects of these on wild organisms and ecosystem functioning
Denmark	Ministry of Environment and Food for fish farms in locations more than 1 nm from the coast, and local municipalities for fish farms under 1 nm from the coast.	Legal Act for Environmental Protection No. 966 af 23.06.2017, and Order for Environmental Permissions No. 1317 af 20.11.2018 and Guideline for seacage farming No. 9163 af 31.03.2006. Legal Act for international nature protection No. 11926.01.2017.	Hydrodynamic model analyses and sediment samples and analyses. Sediment samples for Cu under the nets, up- and downstreams, reference points and other relevant points. Samples and analyses: by independent 3. party firm. Monitoring requirement is dependent on the size and the placement of the fishfarm	Management, net change, use of Dynema nett using les antifouling.	There are no threshold values for chemicals such as copper in the sediment.
Faroe Islands	Environment Agency www.us.fo	Legal Act for Environmental Protection No. 134 af 28.10.1988, and Guideline for Environmental monitoring of Fish farm No. 19/2018	Seabed monitoring at all active sites at maximum biomass as a minimum. Thresholds for cupper and zinc.	Using less antifouling, thresholds of additives in feed	
Germany	State agencies for coastal AC, BSH for EEZ AC	Animal Welfare Law, various regulations on input of chemicals to the environment			Fate of active ingredients and derivates in environment
Ireland	Department of Agriculture Food and Marine (DAFM) - Implements the overall controls relating to dangerous substances in Aquaculture in Ireland	European Communities (Control of Dangerous Substances in Aquaculture) Regulations 2008	No formal monitoring programme is in place. Controls are based upon licensing conditions such that if the practices at the site are such that the site is at risk of exceeding standards identified as a result of modelling the fate of discharges.	Where antifoulants are used to prevent fouling of cages they are usually, copper based. Zinc may also be an active ingredient in some products. Antifoulants are not always used and mechanical cleaning of nets/equipment is often preferred.	Dispersion modelling validation.
Norway	Norwegian Directorate of Fisheries (NDF) and Norwegian Environment Agency	The Aquaculture Act. , requirement for Environmental monitoring (§11). Provides motivation for B- and C-Investigations (Standard: NS 9410:2016). Regulation pursuant to the Act including Aquaculture Operations (together with Food Safety Act.).	Environmental monitoring is conducted both under and close to the farm (the local impact zone) and away from the farm (intermediate impact zone). Benthic impact (indicators) are used to initiate a range of management responses (NS9410:2016). B-investigations target the local zone and utilize a pH/Eh index and a range of sensory parameters, while C-investigations are conducted (less frequently) to assess the outer zone of effect using more detailed benthic indicators (including macrofauna). There are established thresholds for different impact levels (4) associated with increasingly severe management responses (frequency of sampling) employed in response to increases in environmental impacts. If the level of impact exceeds level 3 the authorities decide on mitigating actions. Hardbottom monitoring: Has until now been performed as an alternative survey at the requirement of the authorities. Hardbottom EQS are still under development. Baseline information: detailed baseline surveys now required prior to introducing a new farm. Some long-term regional monitoring occurs in some regions. Otherwise, the authorities determine where and when to perform regional monitoring. Results are considered in the context of the European Water Directive Framework (WDF) guidelines. Also, the recent (2017) BluePlanet initiative (https://www.blueplanet.no/baerekraftig-havbruk) has more detailed monitoring programs in three southern regions. IMR has started a regional monitoring in Hordaland in 2018.	Control of feeding levels / biomass. Farm positioning / repositioning. Undertake good, high-resolution depositional modelling to predict extent of footprint. Closed containment farms (not yet in commercial use). Prohibition of use of Cu as antifoulant for some fish farms.	Effects associated with non-organic component of waste (e.g. copper, therapeutants) are not distinguished or understood. We need more knowledge on effects of organic contaminants both from marine and terrestrial feed sources on different marine organisms and stages. Effect on non-soft-sediment benthic habitats (and species) not well understood. No standardized monitoring system for hard-bottom habitats. Regional / far-field effects are not well understood and difficult to regulate. Lack of historical long-term regional data and poor comprehension of what constitutes pristine baseline conditions.
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt)	DL236/98, altered by DL52/99, DL53/99, DL54/99, DL56/99, DL431/99, DL306/2007, and DL135/2009 Establishes quality standards, criteria and objectives with the purpose of protecting the aquatic environment and improving the quality of the water in relation to its main uses. DL103/2010, altered by DL83/2011, and DL218/2015 Transposes into Portuguese law Directive 2008/105/EC European Parliament and of the Council, on environmental quality standards in the field of water policy, and partially transposes into Portuguese law Directive 2009/90/EC, of the European Parliament and of the Council, on the technical specifications for chemical analysis and monitoring of water status. DL108/2010, altered by DL201/2012, DL136/2013, and DL143/2015 Transposes into Portuguese law Directive 2008/56/EC of the European Parliament and of the Council, establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) DL506/99 Sets the quality standards for certain dangerous substances included in the families or groups of substances in list II of Annex XIX to DL236/98 DL261/2003 Add new substances to DL506/99	Framed into food safety regulations: DL113/2006 Transposes into Portuguese law Regulation (EC) nº 852/2004 and nº 853/2004 of the European Parliament and of the Council on the hygiene of foodstuffs and laying down specific hygiene rules for food of animal origin, respectively P1421/2006 Establishes additional rules for the production and marketing of live bivalve molluscs, echinoderms, tunicates and marine gastropods, complementary to Regulation (EC) nº 852/2004 and nº 853/2004 of the European Parliament and of the Council Regulation (EC) nº 178/2002 of the European Parliament and of the Council Establishes the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety Regulation (EC) nº 1774/2002 of the European Parliament and of the Council Establishes health rules concerning animal by-products not intended for human consumption Regulation (EC) nº 854/2004 of the European Parliament and of the Council Establishes specific rules for the organisation of official controls on products of animal origin intended for human consumption	P276/2017 - Establishes the arrangements and amount of the security deposit needed to ensure good ecological condition the environment and water bodies as well as the removal of any infrastructure at the end of the licensing	No "control" (pristine/baseline) values and no threshold values for new chemicals nor planned withdrawal/depuration strategy. Impact of microplastics (extensive fish farming / from in fish feed)-
UK (Scotland)	Scottish Environment Protection Agency (SEPA)	Water Environment (Controlled Activities) (Scotland) Regulations 2011	Licenced activity. See medicine		
USA	Environmental Protection Agency (EPA) or states authorized by EPA	Clean Water Act - Section 402 establishes the National Pollutant Discharge Elimination System (NPDES) and authorizes EPA (or states authorized by EPA) to issue permits for point source discharges of pollutants into waters of the United States.	Commercial fish farming occurs primarily in the states of Maine and Washington and both these states are authorized by EPA to issue NPDES permits. Sediment monitoring for toxic chemicals include: Maine - the Department of Environmental Protection (DEP) reserves the right to require sediment sampling for copper if copper-containing compounds are used on the nets or related appurtenances that contact the receiving water.		
China	Fisheries governance authorities at all levels	Fisheries Law of China (2004) Article 20 Aquacultural workers shall protect the ecological environment of the waters by scientifically defining the density of aquaculture, and through rational feeding and rational application of fertilizer and use of medicines, and contamination of the waters therefrom is not allowed. Law of the People's Republic of China on the Prevention and Control of Water Pollution (2017) Article 57 Aquaculture activities should protect the ecological environment of the waters, scientifically determine the culture density, reasonably feed and use drugs to prevent pollution of the water environment.	Fisheries Law of China (2004) Article 36: People's governments at all levels shall take measures to protect and improve the ecological environment of fishery waters and prevent pollution. The ecological environment of fishery waters shall be supervised and regulated, and fishery pollution shall be investigated and handled in accordance with the relevant provisions of the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China.	Fisheries Law of China (2004) Article 47: Anyone who damages the ecological environment of the fishery waters or causes fishery pollution shall be investigated for legal liability in accordance with the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China.	There is still a significant lack of knowledge on impact of chemical contaminants in aquaculture waters

Finfish		
	Issue	Effluents
	Sub-issue	Residues of medicine/drugs (Antibiotics, pesticides)
	Description of the sub-issue	Medicines are prescribed and used in fish farms to control pathogens (especially bacteria and parasites), but spread of residues can also have negative impact on wild non-target species

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, Environment and Climate Change Canada, Health Canada, provincial governments	Fisheries Act, Aquaculture Activities Regulations, Canadian Environmental Protection Act (Disposal at Sea provisions, New Substances Notification Regulations), Food and Drug Act, Pest Control Products Act	Federal monitoring program being developed	Product-specific restrictions are included as part of the regulatory approvals, as appropriate. For example, restrictions on the application of certain pesticides (azamethiphos) based on the depth of the site to minimize exposure of the benthic environment. Restrictions on the number of times per year or production cycle that it can be applied.	Persistence in the marine environment; Effects of long-term or multiple exposures during life cycle of non-target species; Effects of exposure to multiple medicines.
Denmark	Environment: Ministry of Environment and Food for fish farms in locations more than 1 nm from the coast, and local municipalities for fish farms under i 1 nm from the coast. Human health and environment: The Danish Veterinary and Food Administration (DVFA) and The Danish Medicine agency.	Legal Act for Environmental Protection No. 966 af 23.06.2017, and Order for Environmental Permissions No. 1317 af 20.11.2018 and Guideline for seacage farming No. 9163 af 31.03.2006. Legal Act for international nature protection No. 119 26.01.2017. Order 1252/2017 om dyreejeres anvendelse af lægemidler til dyr samt offentlig kontrol og fødevarevirksomheders egenkontrol med restkoncentrationer. Order 1253/2017 om dyrlægers anvendelse, udlevering og ordinering af lægemidler til dyr	Hydrodynamic model analyses and sediment samples and analyses. Sediment samples for antibiotic under the nets, up- and downstreams, reference points and other relevant points. Samples and analyses: by independent 3. party firm. Monitoring requirement is dependent on the size, the placement of the fishfarm and if the farm has used medicine. All medicine prescribed by vet. All use of medicine registered in a central database called VetStat. VetStat information is open for the public.	Vaccination, management, location, spacial planning	Development of better vaccines Better vaccination strategies. Lack of medicines
Faroe Islands	Faroese Food and Veterinary Authority www.hfs.fo	Regulation on disease preventive fish farming operation NO. 80 at 14.06.2019Residues Directive (Directive 96/23/EC)	All medicine is prescribed by veterinarians and all use of medicine is registrated	Vaccination, management	Fate of and persistence in the environment
Germany	State agencies for coastal AC, BSH for EEZ AC	Animal Welfare Law, various regulations on input of chemicals to the environment			Fate of active ingredients and derivates in environment
Ireland	The Health Products Regulatory Authority governs the use by veterinarians of medicines used in the treatment of diseases and parasites at finfish farms.	The supply and use of veterinary medicines in Ireland is governed by the Animal Health and Welfare (Animal Remedies Veterinary Practice and Veterinary Medicine) Regulations 2017 (SI 558/2017) which were made under the Animal Remedies Act, 1993. In accordance with the residues directive (Dir. 96/23/EC), monitoring is carried out by the Marine Institute, on behalf of DCMNR, to support consumer protection (food safety), ensure proper use of medicines (e.g. adherence to withdrawal periods), and control use of illegal substances.	Health Products Regulatory Authority. Vets are required to hold records of chemicals, purchased, sold and administered for a 5 year period. Also the farm operators are required to maintain records of animal remedies applied. In accordance with this directive, salmon and trout from fish farms are routinely monitored for the presence of veterinary residues, contaminants and other substances. The purpose is to support consumer protection (food safety), ensure proper use of medicines (e.g. adherence to withdrawal periods), and control use of illegal substances. This legislation and monitoring does not deal with broader environmental issues that may be associated with use of treatments. The sampling strategy depends on the substance. Primarily fish are sampled at harvest to ensure that levels of authorised medicines do not exceed Maximum Residue Levels (MRLs).	Single Bay Management (SBM) - involves all of the farms in an area co-operating to develop an integrated management plan to control outbreaks of parasites and diseases.	The non-statutory nature of SBM plan makes it vulnerable to operators breaking with the protocol. Fate and persistence of chemotherapeutants in environment an ongoing issue, e.g., analysis sensitivity for testing for compounds e.g., emamectin in sediments.
Norway	The Norwegian Medicines Agency , Norwegian Food Safety Authority, Norwegian Environment Agency.	*Aquaculture act* §.1 Specifies Purpose § 10. Environmental goal § 11. requirement for environmental monitoring *Regulations for Aquaculture Operations* § 5. General requirements for operation. § 15. Use of medicines and other chemicals § 15a Conditions for using chitin synthesis inhibitors § 15b. Specific conditions related to bath treatment	There is no monitoring of pharmaceuticals in sediment or biota directed by any governmental institution. Some farmers take the initiative for private investigations.	The laws and regulations aims to reduce the environmental impact om medicine used; E.g. When using drugs and other chemicals, special care must be taken to avoid unacceptable effects on the surrounding environment. There must be an assessment of the local conditions that are important for the spread of drugs in the surrounding environment when treating fish for infestations with salmon lice and a description of organisms in the area that can be adversely affected by such substances. In addition, actions must be described that can be implemented to reduce the negative environmental impact of such substances.	Bath treatment drugs: need more data on spreading, distribution and dilution after discharge and toxicological studies on non-target species. In feed drugs: need more data on distribution around fish farms, persistence in sediment and toxicological studies on non- target species.
Portugal	Veterinary authorities (DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt)	DL148/2008 Establishes the legal regime for the use of veterinary medicine D10015/2012 Approves the list of Authorized Medicinal Food Manufacturers DL314/2009 transposes into Portuguese law 2009/9/EC, amending Directive 2001/82/EC related to veterinary medicinal products D10015/2012 Approves the list of Authorized Medicinal Food Manufacturers DL314/2009 transposes into Portuguese law 2009/9/EC, amending Directive 2001/82/EC related to veterinary medicinal products DL151/2005 Establishes the legal regime for the manufacture, placing on the market and use of medicated feed Approves the medicated feed recipe template, and feed certificate template for trade purposes DL146/2009 Establishes the prohibition of the use of certain hormonal or thyrostatic substances and beta agonists in animal production	Framed into food safety regulations: DL113/2006 Transposes into Portuguese law Regulation (EC) nº 852/2004 and nº 853/2004 of the European Parliament and of the Council on the hygiene of foodstuffs and laying down specific hygiene rules for food of animal origin, respectively supervised by the Food safety authorities (ASAE - Autoridade de Segurança Alimentar e Económica; www.asae.gov.pt)		In feed drugs: effects in fish and bioaccumulation and/or persistence in neighboring-non-target species and sediment
UK (Scotland)	Health and Safety Executive (HSE), Veterinary Medicines Directorate (VMD), Scottish Environmental Protection Agency (SEPA)	Medicines and products used on fish farms are approved and regulated through chemicals legislation (e.g. Biocidal Products Regulations) or veterinary medicines regulations (VMR) by the Health and Safety Executive (HSE) and Veterinary Medicines Directorate (VMD) respectively. Scottish Environmental Protection Agency (SEPA) regulates the discharge of chemicals into the environment through The Water Environment (Controlled Activities) (Scotland) Regulations 2011. SEPA regulates discharges of medicines and chemicals and substances depending on their environmental risk: - substances or products that pose no or low environmental risk and which require no site-specific risk assessment may be added to the Permitted Substances List. - substances or products that do not meet the no or low environmental risk threshold will be added to the permit with conditions controlling use to ensure that environmental standards are met. The permitted substances list (PSL) is produced by SEPA following a screening environmental risk	SEPA regulate the amount of waste discharged into the environment through licences. A revised regulatory framework was introduced in 2019, following a consultation which started in 2017. New requirements were introduced in the revised regulatory framework that are being phased in, some are still in the interim stage. Modelling is used to assess organic loading and dispersal of wastes from sites during the licensing process. During the planning process, the company must produce a Seabed and Water Quality Monitoring Plan (SWMP) that allows SEPA to assess the environmental impact that arises from the farm following the start of production and allows validation of the modelling outputs. SEPA established a quality assurance certification scheme - Measurement Assurance and Certification Scotland (MACS) -to ensure monitoring meets a certain standard. SEPA currently sets limits on the amount of certain sea lice medicines that can be used. SEPA does not currently set limits for vaccines, anesthetics and antibiotics.	Use of predictive models. Licensing process.	Environmental thresholds, far-field effects, modelling, new medicinal or chemical products,
USA	U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS) Food and Drug Administration (FDA) Environmental Protection Agency (EPA) or states authorized by EPA	Virus-Serum-Toxin Act - Veterinary biologics are regulated by APHIS according to the Federal Food, Drug, and Cosmetic Act - FDA regulates drugs given to fish. A list of approved drugs for aquaculture can be found at: https://www.fda.gov/animal- veterinary/aquaculture/approved-aquaculture-drugs Clean Water Act - Section 402 establishes the National Pollutant Discharge Elimination System (NPDES) and authorizes EPA (or states authorized by EPA) to issue permits for point source discharges of pollutants into waters of the United States.	NPDES permit may require monitoring for therapeutants and their breakdown products in benthos or water quality sampling. Pollutant discharges allowed from the facility include FDA-approved medications.	In an effort to ensure the judicious use of medically-important antimicrobials in feed or water for food-producing animals, the FDA issued a final rule, effective October 1, 2015, revising the Veterinary Feed Directive (VFD), which is a category within the Animal Drug Availability Act. The VFD now requires that therapeutic use of these drugs in or on animal feed or in water be supervised by a licensed veterinarian and provides veterinarians in all states with a framework for authorizing use for specific animal health purposes.	
China	Ministry of Agriculture and Rural Affairs (MARA), Bureau of Fisheries (BF), Bureau of Veterinary (BV), National Medical Products Administration (NMPA)	BV and BF of MARA regulates drugs given to fish according to Veterinary Drugs Management Regulations - Section 6. Units using drugs will abide by the regulations on the safe use of veterinary drugs formulated by the administrative department for veterinary medicine of the State Council, and establish drug use records. MARA establishes the National Standard of "Discharge Requirements for Marine Aquaculture Effluents" and "Discharge Requirements for Freshwater Pond Farming Effluents"	For monitoring of veterinary drug residues, promote scientific, safe and rational use of drugs in the aquaculture, and ensure the safety of animal- derived food, MARA organized the "Animal and animal product veterinary drug residue monitoring plan" every year. Pollutant discharges allowed from the facility include MARA-approved standard.	With reference to international standards and European and American standards, the MARA has also formulated and issued China's "Maximum Limits for Veterinary Drug Residues in Foods of Animal Origin"	

Finfish	**Issue**	Effluents
	Sub-issue	Effects on sensitive habitat
	Description of the sub-issue	Tolerance limits of sensitive habitats exposed to fish farm waste and such knowledge on safe distance to farms.

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada	Fisheries Act		Appropriate siting to avoid locating farms over or near sensitive habitats.	
Denmark	Ministry of Environment and Food for fish farms in locations more than 1 nm from the coast, and local municipalities for fish farms under 1 nm from the coast.	Legal Act for international nature protection No. 119 26.01.2017. Order for protection of nature and habitats No. 1240 24.10.2018		Location, spatial planning	
Faroe Islands	Ministry of Environment, Industry and Trade; Environment Agency and; Faroese Food and Veterinary Authority	Legal Act for fish farming No.65 25.05.2009.		Appropriate siting, hearing of various third parties when new licences are given	
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible for the overall licencing and management of finfish aquaculture in Ireland; The Marine Institute (MI) provides scientific advice on a range of marine environment and aquaculture matters and in the case of applications which require Appropriate Assessment (AA) under EU Birds and Habitats Directives, the MI prepares scientific reports. Management of conservation sites (SACs, SPAs, and setting of objectives is carried out	The Fisheries (Amendment) Act 1997 and its associated Regulations set out the framework for the processing of Aquaculture licensing operations. European Communities (Birds and Natural Habitats) Regulations 2011 (S.I. No. 477 Of 2011). Birds Directive: Directive 74/409/EEC on the conservation of wild birds. Habitats Directive: Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.	Site specific monitoring conditions may be imposed on licences to monitor specific measures enacted to mitigate against impact on conservation features. Article 12 and 17 monitoring of the EU regulations which require reporting every 6 years on the conservation status of features and a commentary on the potential threats (including aquaculture operations).	A range of mitigation measures may apply to licences that are designed to minimise impacts on conservation features.	Cumulative effects when assessing impacts. Detailed conservation objectives to identify specific habitat and species sensitivities.
Norway	Norwegian Environment Agency	Act regulating management of nature and biodiversity 2009, Several regulations on conservation of coral reefs and MPA.	There is currently no specific monitoring of sensitive habitats close to finfish farms in Norway.	According to the Norwegian Standard NS 9410:2016 an investigation of the environment is obligatory before establishment of a new farm or expansion of an existing. Nature type mapping of the area to avoid impact on sensitive habitats might be included in these pre- investigations if demanded by the authorities. There is currently no standardized guidelines or thresholds set for such investigations. Several of the large coral reefs along the Norwegian coast is under protection.	There is currently little knowledge on tolerance limits of sensitive habitats exposed to fish farm waste and such knowledge on safe distance to farms. Work is in progress at IMR to improve knowledge on impact and dispersal of various waste substances on sensitive and important habitats.
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt) ICNF - Instituto da Conservação da Natureza e das Florestas (Institute for Nature Conservation and Forestry; www.icnf.pt) if in classified areas	DL140/99, altered by DL49/2005, and DL156-A/2013 Transposes into Portuguese law the Directive nº 79/409/CEE on the conservation of wild birds and Directive nº 92/43/CEE on the conservation of natural habitats and of wild fauna and flora RCM115-A/200 Approves the Plan for the Natura 2000 Network in continental Portugal DL142/2008 Establishes the legal framework for the conservation of nature and biodiversity, ICNF. DL166/2008 Approves the legal framework for the National Ecological Reserve (REN) P1356/2008 Establishes the conditions for the viability of the uses and actions referred to in number 2 and 3 of article 20.º of DL166/2008 (namely IV. Aquaculture)	if in the context of point IV of P1356/2008, licensing requires prior approval by the DGPA - Direcção-Geral das Pescas e Aquicultura (Directorate for Fisheries & Aquaculture of the Portuguese Government) in the case of Marine Aquaculture or DGRF - Direcção-Geral dos Recursos Florestais (Directorate for Forestry Resources) in the case of inland aquaculture		
UK (Scotland)	Scottish Environment Protection Agency	Water Environment (Controlled Activities) (Scotland) Regulations 2011, Aquaculture and Fisheries (Scotland) Act 2013, planning legislation	During the planning and licensing process, as part of the EIA, the potential impact on sensitive habitats would be assessed. SEPA do not permit farms that would have mixing ones extending into areas where the conservation status of marine protected areas (MPAs) or priority marine features (PMFs) could be affected.	Appropriate site selection.	Impact of aquaculture on sensitive habitats
USA	National Oceanic and Atmospheric Administration (NOAA), U.S. Fish and Wildlife Service (USFWS)	Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA) - requires federal permitting agencies consult with NOAA regarding effects on Essential Fish Habitat. Endangered Species Act (ESA) requires that federal permitting agencies consult with NOAA and USFWS if threatened or endangered species or their critical habitat may be affected.	While there are no requirements to establish monitoring under MSFCMA or ESA, recommendations may be provided depending upon the specific project.	Legislation in place provides protection preventatively at the siting and permitting stage where mitigation should not, in theory, be needed.	The industry in the U.S. is small and at its early stage of development. As the industry establishes, there will be a need to understand how specific farm designs affect the natural habitats where they are located.
China	Fishery Law of the People's Republic of China Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China	Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China, Article 12: The natural spawning grounds, nursery grounds, feeding grounds and important migration passages of fish, shrimp, crabs, shellfish, and algae in the public owned water surface and tidal flats must be protected, and shall not be planned or used for aquaculture. Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China, Article 10: All the public owned and collectively-owned units engaged in aquaculture production by using public owned water surfaces and tidal flats, shall apply to the local people's government at or above the county level for an aquaculture permit. Fishery Law of the People's Republic of China (2004) Article 37: The State maintains special protection of the rare and endangered aquatic wild animals such as white-flag dolphin to prevent them from extinction. Killing and attacking of important aquatic wild animals protected by the State is prohibited. Where it is necessary to catch such animals for purposes of scientific research, taming and propagation, exhibition or for other special purposes, the matter shall be dealt with in accordance with the provisions of the Law of the People's Republic of China on the Protection of Wildlife.	Fishery Law of the People's Republic of China (2004) Article 28: The administrative departments for fisheries under the people's governments at or above the county level shall work out overall plans and take measures to increase the fishery resources in the fishery waters under their jurisdiction. They may collect fees from the enterprises and individuals profiting from the use of such waters and devote the money thus collected to the increase and protection of the fishery resources. Measures for collecting such fees shall be formulated by the administrative department for fisheries together with the department of finance under the State Council and shall go into effect upon approval by the State Council.	Fishery Law of the People's Republic of China (2004) Article 29: The State protects the aquatic species and their living environment and establishes aquatic species protection zones in the main areas where aquatic species of high economic and hereditary breeding value grow and propagate. No unit or individual may engage in fishing in the protection zones without the approval of the administrative department for fisheries under the State Council.	Some research done on sensitive habitats, but not so much in relation to aquaculture

Finfish	**Issue**	Effluents
	Sub-issue	Water column impacts: Nutrification
	Description of the sub-issue	Fish excretion releases large quantities of nutrients (ammonia, nitrates) to the water column which can result in eutrophication. Phytoplankton blooms can be stimulated and can result in a change in trophic state

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada					Contribution of farm-derived nutrients to nutrient pools and cycling, including potential contribution to eutrophication, unknown.
Denmark	Ministry of Environment and Food for fish farms located more than 1 nm from the coast, and local municipalities for fish farms under 1 nm from the coast.	Legal Act for Environmental Protection No. 966 af 23.06.2017, and Order for Environmental Permissions No. 1317 af 20.11.2018 and Guideline for seacage farming No. 9163 af 31.03.2006. Legal Act for international nature protection No. 119 26.01.2017	Hydrodynamic model analyses caried out by the farm. Water quality monitoring is caried out by the authority due to the requirement after the Water Frame Directive.	Location, spacial planning, management, production quota	
Faroe Islands	Environment Agency www.us.fo	Legal Act for Environmental Protection No. 134 af 28.10.1988	Some research projects are aiming to deduct the amount of nutrients from fish farms and possible eutrophication effects	Site selection	Contribution of farm derived nutrients to eutrophication
Germany	Coastal Zone: State Agencies; EEZ: BSH (Federal Office of Navigation and Hydrography)	EU-Regulations, Federal and state laws on environmental protection, Water law		Stocking density, Feed quality, Site selection	
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible for the overall licencing and management of finfish aquaculture in Ireland; The Marine Institute is responsible for reviewing annual benthic reports from fish farm sites and reporting toDAFM.	Monitoring set out under Licence conditions - Fisheries (amendment) Act 1997:	Water quality monitoring is carried out at all active sites on an annual basis according to the Monitoring Protocol No. 2-for Offshore Finfish Farms - Water column Monitoring (subject to revision from time to time) - 11 May 2001. (https://www.agriculture.gov.ie/seafood/aquacultureforeshoremanagement/marinefinfishprotocols/)	Resurvey, fallowing, stocking and feed control.	Monitoring compliance in an ongoing issue? Effectiveness of monitoring, sensitivity of sampling and effects of levels of nutrient on surrounding environment.
Norway	Norwegian Directorate of Fisheries (NDF) and Norwegian Environment Agency	Regulations and framework for management of water quality 2007. The Aquaculture Act. Specifies Purpose (§1), Environmental Standards (§10), Water quality (§22, 23).	Long-term (2013-) trend monitoring of water quality in coastal waters is regularly performed at 140 stations along the Norwegian coast. Biological (phytoplankton biomass, seaweed composition and infauna in soft sediment) as well as physical support-parameters is measured according to guidelines following the EU water frame work directive (ØKOKYST). Additionally, a more extensive (denser station net) sampling program (2010-2020) is performed in areas with high fin-fish production in the counties of Hordaland, Rogaland and Nordland following the same guidelines. The latter program is initiated and financed by the farming companies in the area. Biomass and composition of phytoplankton in coastal waters is frequently monitored on a high number of stations to be able to warn the public and industry about toxic species and harmful algal bloom. Results are available here: http://algeinfo.imr.no/. There is currently no monitoring of nutrification or impact of nutrients in the farms influence zone.	Control of feeding levels (biomass). Farm siting - dispersive water bodies. IMTA has the potential to mitigate water column enrichment, but the effectiveness it yet to be properly demonstrated and is not currently in use. Closed containment farms (not yet in commercial use). Increased use of hydrodynamic and dispersion models to improve site placement with respect to avoiding non-dispersive water bodies or overlapping discharge plumes.	Contribution of farm derived nutrients to low DO levels in some fjords (with sills). Remains some uncertainty around potential for low-level effects on plankton and macroalgae in the vicinity of farms. Positive, neutral or negative?
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt)	DL226-A/2007, altered by DL391-A/2007, DL93/2008, DL107/2009, DL245/2009, DL82/2010, and L44/2012 Establishes the framework for the use of water resources DL38/2015 Develops L17/2014 which establishes the Bases of the Planning and Management Policy of the National Maritime Space, defining among other: b) legal framework applicable to titles of private use of the national maritime space (TUPEM); d) system for permanent monitoring and technical evaluation of the planning of the national maritime space; and e) system of private use of water resources in transitional waters for aquaculture purposes. L58/2005, altered by DL245/2009, DL26/2010, and DL130/2012 Approves the Water Law, transposing into Portuguese law the Directive 2000/60/EC of the European Parliament and of the Council and laying down the foundations and institutional framework for sustainable water management DL77/2006 Complements the transposition to Directive 2000/60/EC of the European Parliament and of the Council P276/2017 Establishes the arrangements and amount of the security deposit needed to ensure good ecological condition the environment and water bodies as well as the removal of any infrastructure at the end of the TAA.	DL236/98, altered by DL52/99, DL53/99, DL54/99, DL56/99, DL431/99, DL306/2007, and DL135/2009 Establishes quality standards, criteria and objectives with the purpose of protecting the aquatic environment and improving the quality of the water in relation to its main uses. DL103/2010, altered by DL83/2011, and DL218/2015 Transposes into Portuguese law Directive 2008/105/EC European Parliament and of the Council, on environmental quality standards in the field of water policy, and partially transposes into Portuguese law Directive 2009/90/EC, of the European Parliament and of the Council, on the technical specifications for chemical analysis and monitoring of water status. Specific requirements can be included into the Environmental impact assessment (case-by-case basis) DL151-B/2013, altered by DL47/2014 and DL179/2015 - Legal framework for the assessment of the environmental impact of public and private projects (transposing into Portuguese law the Directive 2011/92/EU) P395/2015 - Establishes the formal technical requirements to be followed by the procedures provided for in the legal regime for environmental impact assessment	P368/2015- Establishes fees to be charged by the authorities under the environmental impact assessment procedure P276/2017 - Establishes the arrangements and amount of the security deposit needed to ensure good ecological condition the environment and water bodies as well as the removal of any infrastructure at the end of the licensing	Lack of "control" (unaltered/pristine) environment for the establishment of "good" status No follow-up / continuous monitoring of discharges and consequent modelling
UK (Scotland)	Scottish Environmental Protection Agency (SEPA)	Water Environment (Controlled Activities) (Scotland) Regulations 2011, Aquaculture and Fisheries (Scotland) Act 2013	SEPA regulate the amount of waste discharged into the environment through licences. A revised regulatory framework was introduced in 2019, following a consultation which started in 2017. New requirements were introduced in the revised regulatory framework that are being phased in, some are still in the interim stage. Modelling is used to assess organic loading and dispersal of wastes from sites during the licensing process. During the planning process, the company must produce a Seabed and Water Quality Monitoring Plan (SWMP) that allows SEPA to assess the environmental impact that arises from the farm following the start of production and allows validation of the modelling outputs. SEPA established a quality assurance certification scheme - Measurement Assurance and Certification Scotland (MACS) -to ensure monitoring meets a certain standard.	Site selection, licensing process	
USA	Environmental Protection Agency (EPA) or states authorized by EPA	Clean Water Act - Section 402 establishes the National Pollutant Discharge Elimination System (NPDES) and authorizes EPA (or states authorized by EPA) to issue permits for point source discharges of pollutants into waters of the United States. Effluent Limitation Guidelines are established for Concentrated Aquatic Animal Production facilities, including marine net pen aquaculture producing 100,000 pounds or more of aquatic animals per year (40 CFR Part 451).More information can be found at: https://www.epa.gov/eg/concentrated-aquaticanimal-production-effluent-guidelines; http://www.ecfr.gov/cgi- bin/text-idx?SID=b32f065c3e56d423dbc1858e2a077818&mc =true&node=pt40.32.451&rgn=div5#sp40.32.451.b	Commercial fish farming occur primarily in the states of Maine and Washington and both these states are authorized by EPA to issue NPDES permits. Water column monitoring requirements for these two states include: Maine - the Department of Environmental Protection (DEP) requires establishment of a Water Column Mixing Zone and is defined as the area within and extending 30 meters beyond the perimeter of a net pen in all directions on the surface, and down to the sea floor/water column interface. The dissolved oxygen concentration within the water column mixing zone must not be lower than 6 mg/L at any point from the surface down to the sea floor/water column interface. DEP reserves the right to require routine or periodic dissolved oxygen monitoring. Other water quality parameters within the water column mixing zone must comply with the applicable standards specified at Standards for classification of marine and estuarine waters, 38 M.R.S.A. § 465-B. Washington - the Department of Ecology manages Section 402 NPDES permits that require water quality monitoring, a pollution prevention plan, and reporting. More information can be found at: http://www.ecy.wa.gov/programs/wq/permits/i ndex.html.	Prevention through proper site selection and stocking densities.	
China	Marine Environment Monitoring Centre of the State Oceanic Administration (now of the Ministry of Ecology and Environment), local Ocean and Fisheries Bureau are the agencies responsible for monitoring water column	Fisheries Law of China (2004) Article 20 Aquacultural workers shall protect the ecological environment of the waters by scientifically defining the density of aquaculture, and through rational feeding and rational application of fertilizer and use of medicines, and contamination of the waters therefrom is not allowed. Law of the People's Republic of China on the Prevention and Control of Water Pollution (2017) Article 57 Aquaculture activities should protect the ecological environment of the waters, scientifically determine the culture density, reasonably feed and use drugs to prevent pollution of the water environment.	-Fisheries Law of China (2004) Article 36: People's governments at all levels shall take measures to protect and improve the ecological environment of fishery waters and prevent pollution. The ecological environment of fishery waters shall be supervised and regulated and fishery pollution shall be investigated and handled in accordance with the relevant provisions of the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. Some research projects include water quality survey and long-term monitoring of aquaculture areas.	Fisheries Law of China (2004) Article 47: Anyone who damages the ecological environment of the fishery waters or causes fishery pollution shall be investigated for legal liability in accordance with the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. Aquaculture spatial planning; Appropriate siting and culture density.	We already know that nutrient load / eutrophication may cause HAB and hypoxia. However, there are still knowledge gaps on impact of eutrophication on water column and the benthic environment and communities.

Finfish	**Issue** **Sub-issue** **Description of the sub-issue**	Pathogens/parasite transfer Virus & bacteria Viral and viral diseases can be spread from farmed fish and cause mortality on different species of wild fish			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Canadian Food Inspection Agency, Fisheries and Oceans Canada, provinces	Health of Animals Act Fisheries Act, Pacific Aquaculture Regulations	National Surveillance of Aquatic Animal Diseases (see https://www.inspection.gc.ca/animal-health/aquatic- animals/diseases/surveillance/eng/1322933174051/1322933270922)	Fish health management practices at the farm level (farm veterinarians and fish health experts)	Extent that susceptible wild species of fish are found near farms to characterize their exposure to pathogens from finfish farms; susceptibility of wild fish to pathogens from farms; pathogen shedding rates to support modelling of infection pressures; Infection rates (prevalence) on farms; Enhanced early diagnostics (e.g., BKD); Pathogen decay rates and parameters in the marine environment; Contributing factors to the development of disease (e.g., environmental conditions); The experts in the ICES WGPDMO is MUCH better placed to identify the knowledge gaps - this should be left to them.
Denmark	The Danish Veterinary and Food Administration (DVFA)	All movement of fish and management of fish disease is strict regulated. Basic EU legislation: Council Directive 2006/88/EC of 24 October 2006 on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals. Implemented i DA legislation: Order 965/2013 om authorisation og drift af akvakulturbrug samt om omsætning af akvatiske organismer og produkter deraf. Order 967/2013 om overvågning og registrering af Infektiøs pankreasnekrose (IPN) og Bakteriel nyresyge (BKD). Order 1324/2015 om overvågning og bekæmpelse af visse smitsomme sygdomme hos akvatiske organismer.	Regular farm visits by officially veterinarians from The Danish Veterinary and Food Administration (DVFA).	Denmark have private fish veterinarian expert on fish disease. In all cases of raised mortality on the fish farm the farmers is obliged to contact the private vet.	Very few gaps. The areas is strictly controlled and the Danish marine farmers have very few problems with fish diseases. Sea lice is not a problem in Danish farms due to farming in relatively low salinity.
Faroe Islands	Faroese Food and Veterinary Authority	Act of animal helth 16 23.02-2001,Regulation on disease preventive fish farming operation NO. 80 at 14.06.2019	Regular farm visits from the Faroese Food and Veterinary Authority	Mandatory surveys of listed pathogens and mandatory reporting of outbreaks, detailed regulations on management of fish farming sites, mandatory fallowing, tracking of movement of equipment and fish	
Germany					
Ireland	The Marine Institute is the competent authority for the implementation in Ireland of Council Directive 2006/88/EC, which deals with the health of aquaculture animals and the prevention and control of certain aquatic diseases.	Council Directive 2006/88/EC	The Marine Institute implements a fish health monitoring programme which tests for diseases listed under Directive 2006/88/EC and other aquatic diseases of national importance. Exotic diseases are not currently found within the EU and must be eradicated. Non-exotic diseases are generally confined to certain parts of the Community, whilst other areas remain free. The approach to the eradication of non-exotic diseases, should they appear in Ireland, will be decided by the Competent Authority, on a case-by-case basis	Diseases outbreaks are managed on a case-by case basis. Fallowing of sites is applied according to the Protocol for Fallowing at Offshore Finfish Farms (subject to revision from time to time) 11 May, 2000 (https://www.agriculture.gov.ie/seafood/aquaculturefo reshoremanagement/marinefinfishprotocols/)	
Norway	Norwegian Food Safety Authority, Norwegian Environment Agency,	Food Law: § 1: Specific purpose: Healthy animals § 13: NFSA can take samples to prevent diseases. § 19: Everybody has to be careful to prevent spreading of contagious animal diseases by making zones, restrictions on moving animals, classifying of diseases etc. Animal Welfare Law: § 1: Specific purpose is good animal welfare and respect for all animals (wild and farmed). § 8: Management and equipment must be made in a way that ensures good ani- mal welfare Animal Health Personnel Law: § 1: Such personnel must do their job in a proper way, ensuring good animal health and welfare. Diversity Law: § 1: Specific purpose: Careful and sustainable use of nature, ensuring ecological diversity. Regulation for: Production areas § 8: The total capacity in a production area is decided on the basis on impact on the environment, mainly the effect from sea lice on wild fish. § 9: If the lice-induced mortality on wild fish is unacceptable the government can reduce the capacity in a production area Diseases and placing on the market § 1: specific purpose: Healthy aquatic animals. § 27: warning when listed disease is suspected § 28: Restriction on moving fish, making specific zones. Attachments: Listed diseases (sea lice is a list 3 disease), sampling etc. Sea lice § 1: Specific purpose: Reduce the sea lice load in order to minimize the harm on both farmed and wild fish. Reduce the development on resistance against delousing medicines. § 4: Sea farms must have a plan for prevention and reducing the number of sea lice. Sea farms in a defined area must collaborate on certain measures. § 5: NFSA can make local regulations with defined zones. § 8: There is a maximum limit for number of sea lice on each sea lice. The farmers have to count every week and report to NFSA operation in aquaculture, transport § 1: Specific purpose: Healthy aquatic animals, sustainability	There is currently no national monitoring of spread of virus and bacteria from farms to wild fish in Norway, although mapping of virus in wild fish are done in some regions	Making decisions on the basis of legislation * reducing the biomass * making zones with all inn - all out regime with 2 months of fallowing.	How to monitor the impact from viruses and bacteries more precise than today
Portugal	Veterinary authorities (DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt)	DL152/2009 Transposes into Portuguese law Directive 2006/88/EC of the European Parliament and of the Council on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals D25485/2009 Establishes the rules of transport of aquaculture products and mandatory notification to the DGAV all movements of aquaculture animals and products.	Framed into food safety regulations: DL113/2006 Transposes into Portuguese law Regulation (EC) nº 852/2004 and nº 853/2004 of the European Parliament and of the Council on the hygiene of foodstuffs and laying down specific hygiene rules for food of animal origin, respectively supervised by the Food safety authorities (ASAE - Autoridade de Segurança Alimentar e Económica; www.asae.gov.pt)		
UK (Scotland)	Fish Health Inspectorate, Marine Scotland	Aquaculture and Fisheries (Scotland) Act 2013, The Aquatic Animal Health (Scotland) Regulations 2009 (implementing EU council directive 2006/88/EC)	Fish health inspectors advise and assist in compliance with the regulations including monitoring and testing of fish. The Fish Health Inspectors are responsible for fish disease surveillance in Scotland, including detection of increased mortality and operate a surveillance scheme at all sites Most visits are prearranged but there is a statutory requirement for the inspectorate to carry out unannounced inspections under the EC Directive 2006/88/EC, EC Regulation 882/2004 and The Aquatic Animal Health (Scotland) Regulations 2009.	Site visits. Fish health managed at a local level and more widely in disease management areas.	

USA	U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS) U.S. Fish and Wildlife Service (USFWS)	Animal Health Protection Act - APHIS is lead agency and has accredited private practice veterinarians who can endorse health certificates for transport of animals and for disease management under the Animal Health Protection Act. APHIS collaborates with state and Canadian agencies in developing Infectious Salmon Anemia Program Standards (ISA). More information can be found at: https://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/downloads/isa_standards.pdf Injurious Wildlife Regulations of the Lacey Act - all live salmonid fish and their eggs and dead whole, uneviscerated salmonids imports into the United States must be inspected by a USFWS-certified fish pathologist, fish health inspector, or veterinarian, who then certifies the shipment as disease free.	If a World Organization for Animal Health (OIE)-listed pathogen is confirmed in finfish, then operators are obligated to report to the appropriate APHIS office. Maine - Maine Department of Marine Resources has a regulation of the importation of live marine organisms. The salmonid fish health inspection regulations prohibit clinically diseased salmonid fish from being introduced into Maine's coastal waters. Active and passive pathogen surveillance is required for spawning broodstock and production stock. Producers in Maine are doing routine monitoring on various pathogens. Follow-up monitoring is required if a pathogen is found.		
China	Ministry of Agriculture and Rural Affairs (MARA), Bureau of Fisheries (BF); Bureau of Veterinary (BV);	National Aquatic Technology Extension Station(NATES), under the BF of MARA, incharge the National Monitoring Network for Aquatic Disease.NATES conducts the seeding quarantine in origin area action by which banning cross-regional transportation of aquatic seedlings carrying viruses.	If a World Organization for Animal Health (OIE)-listed pathogen is confirmed in aquaculture animal, then operators are obligated to report to the appropriate local and provincial NATES office.	MARA will announce the list of farms showing both aquatic animal disease negative and positive in the national surveillance, for help of cutting the transmission of pathogens.	

Finfish	**Issue**	Pathogens/parasite transfer
	Sub-issue	Parasites
	Description of the sub-issue	Spread of parasites is one of the main challenges in open cage aquaculture, e.g spread of salmon lice from Atlantic salmon farming causing mortality on wild s

Country	Responsible agencies	Laws and regulations	Monitoring	Mitigation	Knowledge Gap
Canada	Fisheries and Oceans Canada, provincial governments	Fisheries Act, Pacific Aquaculture Regulations, provincial regulations	On-farm sea lice counts by veterinarians or fish health officials. Provincial veterinarian oversight (in BC - it's Fisheries and Oceans Canada)	Veterinarian prescribed treatment for sea lice based on professional decisions	Impact on wild salmonids; sources of sea lice resulting in infestations (given the low number of returning wild salmonids); effect and efficacy of new treatments.
Denmark	The Danish Veterinary and Food Administration (DVFA)	All movement of fish and management of fish disease is strict regulated. Basic EU legislation: Council Directive 2006/88/EC of 24 October 2006 on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals. Implemented i DA legislation: Order 965/2013 om authorisation og drift af akvakulturbrug samt om omsætning af akvatiske organismer og produkter deraf. Order 967/2013 om overvågning og registrering af Infektiøs pankreasnekrose (IPN) og Bakteriel nyresyge (BKD). Order 1324/2015 om overvågning og bekæmpelse af visse smitsomme sygdomme hos	Regular farm visits by officially veterinarians from The Danish Veterinary and Food Administration (DVFA).	In Denmark we have private fish veterinarian expert on fish disease. In all cases of raised mortality on the fish farm the farmers is obliged to contact the private vet.	Very few gaps. The areas is strictly controlled and the Danish marine farmers have very few problems with fish diseases. Sea lice is not a problem in Danish farms due to farming in relatively low salinity.
Faroe Islands	Faroese Food and Veterinary Authority www.hfs.fo	Regulation on monitoring and mitigation of sea lice on farmed fish No. 75 at 28.06.2016	Sea lice are counted counts by a third party fortnightly at all cages at all farms	Veterinarian prescribed treatment for sea lice, mechanical treatments, cleaner fish. Penalty points and regulation on allowed number of fish based on how often sea lice counts are over threshold and the number of treatments	Sea lice transmission between farms, stock assessment of wild salmonids and impact
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of finfish aquaculture in Ireland. The Marine Institute is the competent authority for the implementation in Ireland of Council Directive 2006/88/EC, which deals with the health of aquaculture animals and the prevention and control of certain aquatic diseases.	Council Directive 2006/88/EC govern fish health regulations. Monitoring of sea lice set out under Licence conditions - Fisheries (amendment) Act 1997:	The Marine Institute implements a fish health monitoring programme which tests for diseases listed under Directive 2006/88/EC and other aquatic diseases of national importance. Exotic diseases are not currently found within the EU and must be eradicated. Non-exotic diseases are generally confined to certain parts of the Community, whilst other areas remain free. The approach to the eradication of non-exotic diseases, should they appear in Ireland, will be decided by the Competent Authority, on a case-by-case basis. Sea lice levels are monitored at all sites according to the Monitoring Protocol No. 3 for Offshore Finfish Farms Sea Lice Monitoring and Control (subject to revision from time to time) - May 2001. (https://www.agriculture.gov.ie/seafood/aquacultureforeshoremanageme nt/marinefinfishprotocols/)	Diseases outbreaks are manged on a case-by case basis while Single Bay management is specifically is used for sea lice control and involves all of the farms in an area co- operating to develop an integrated management plan to control outbreaks of parasites and diseases. A specific strategy was initiated in 2008 - (https://www.agriculture.gov.ie/media/migration/seafood/aquacultureforeshorema nagement/marinefinfish-protocols/AStratImprovPestCont2008271113.pdf). In addition, fallowing of sites is applied according to the Protocol for Fallowing at Offshore Finfish Farms (subject to revision from time to time) 11 May, 2000 (https://www.agriculture.gov.ie/seafood/aquacultureforeshoremanagement/marinef infishprotocols/). The use of cleaner fish is also an important mitigation measure with wrasse and lumpfish the species of choice.	Linking parasite occurrence on farms to impact on wild stocks - ongoing issue. In relation to wild-caught cleaner fish (Wrasse species), the impacts on wild stock has yet to be fully understood and appropriate management measures proposed.
Norway	Norwegian Food Safety Authority (NFSA), Norwegian Environment Agency (NEA)	See Sub-issue: Virus & bacteria	A national programme is monitoring sea lice levels on wild salmonids along in the 13 production areas in Norway, and the impact on wild salmonids are estimated.	Making decisions on the basis of legislation: -reducing the biomass in production areas with large sea lice loads. -reducing the amount of sea lice in individual sea farms. -making zones with all inn - all out regime with 2 months of fallowing.	How to monitored the impact from sea lice and other pathogens in even more precise than today
Portugal	Veterinary authorities (DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt)	DL152/2009 Transposes into Portuguese law Directive 2006/88/EC of the European Parliament and of the Council on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals D25485/2009 Establishes the rules of transport of aquaculture products and mandatory notification to the DGAV all movements of aquaculture animals and products.	Framed into food safety regulations: DL113/2006 Transposes into Portuguese law Regulation (EC) nº 852/2004 and nº 853/2004 of the European Parliament and of the Council on the hygiene of foodstuffs and laying down specific hygiene rules for food of animal origin, respectively supervised by the Food safety authorities (ASAE - Autoridade de Segurança Alimentar e Económica; www.asae.gov.pt)		
UK (Scotland)	Fish Health Inspectorate, Marine Scotland	Aquaculture and Fisheries (Scotland) Act 2013, The Aquatic Animal Health (Scotland) Regulations 2009	Companies must report weekly average adult female sea lice numbers when a specified reporting level is reached and through FHI surveillance. https://www.gov.scot/publications/fish-health-inspectorate-sea-lice- information/	Site selection, farm management strategies, treatment. If sea lice numbers are not considered to be bought under control then an enforcement notice can be issued.	
USA	U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS)	Animal Health Protection Act - APHIS is the lead federal agency for disease management and collaborates with state and Canadian agencies in developing Infectious Salmon Anemia Program Standards (ISA). More information can be found at: https://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/downloads/isa_sta ndards.pdf	Upon enrolment in ISA program, operator must submit an Integrated Pest Management Plan for the control of sea lice on salmonids. Maine - aquaculture permits require following the ISA which include the participation in the Integrated Pest Management Program for the Control of Sea Lice. Washington - Sectoin 402 of the National Pollution Discharge Elimination System permit requires reporting of incidence of sea lice infestations. A permit is required to transport finfish aquaculture products into or within Washington. More information can be found at: https://apps.leg.wa.gov/wac/default.aspx?cite=220-370-190	Proper siting and seasonal timing production cycles to avoid coinciding with wild salmon runs near the farm. Washington - Fallowing is done voluntarily which contributes to sea lice control. When the Department of Ecology asks for changes to address infestations. A person is guilty of unlawful transport of finfish in the second degree if they conduct import, export, or intra-state transport of marine finfish without an approved marine finfish aquaculture permit. More information can be found at: https://apps.leg.wa.gov/RCW/default.aspx?cite=77.15.290	Understanding transmission of lice to wild populations.
China	Ministry of Agriculture and Rural Affairs (MARA), Bureau of Fisheries; MARA Bureau of Veterinary	National Aquatic Technology Extension Station(NATES) is the lead national agency for disease management.	Parasites is in list of National Monitoring Network for Aquatic Diseases.		

Finfish	**Issue**	Genetic and ecological issues
	Sub-issue	Escapes
	Description of the sub-issue	Escape of domesticated fish into wild populations, and their subsequent spawning and introgression, represents a threat to the genetic integrity, productivity and long-term viability of wild populations.

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada	Species at Risk, Fisheries Act, Fisheries (General) Regulations	Ad-hoc, often associated with research studies, conservation of wild Atlantic salmon projects or programmes, etc.	Counting fences to intercept escapees on some rivers	Full extent and consequences of both direct and indirect genetic interactions on wild salmon populations in Atlantic Canada. While tools and characterization of hybridization, introgression, F1 and F2 backcrosses in some salmon populations in Newfoundland and Labrador have been completed, the full extent of genetic impacts and specific impact on population dynamics has not been chacterized. Additionally, research is ongoing related to changes in demographics within populations. More information on the knowledge gaps generally and specifically for all ICES member countries farming salmon have been assessed and reported on through ICES advice to NASCO and OSPAR and as part of the work undertaken by the ICES WGAGFA.
Denmark	Ministry of Environment and Food for fish farms in locations more than 1 nm from the coast, and local municipalities for fish farms under 1 nm from the coast.	Legal Act for international nature protection No. 119 26.01.2017. Order for protection of nature and habitats No. 1240 24.10.2018		Regular control of the net, management	
Faroe Islands	Faroese Food and Veterinary Authority www.hfs.fo	Regulation on disease preventive fish farming operation NO. 80 at 14.06.2019	Farmers report escape events and shall try to recapture the fish	Design of equipment according to the physical stress at the locations, regular inspection of net cages.	Impact of fish farm escapes on wild salmonids
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of finfish aquaculture in Ireland	Licence conditions - Fisheries (amendment) Act 1997: Containment system standards defined by Protocol for Structural Design of Marine Finfish Farms (subject to revision from time to time) April 2016.	Licence conditions dictate that operators should do all within their powers to prevent escapes. Monitoring is carried out by DAFM Engineering Division to ensure that fish containment systems are adequate.	Operators must contact DAFM, the Marine Institute and Inland Fisheries Ireland within 24hours in the event of an escape. A suitable management plan (which may include recapture) will be agreed among the relevant parties.	The impacts of fish farms escapees on wild-stocks is currently the subject of considerable academic research - much of which has yet to translate into management practices or actions.
Norway (text relates to Atlantic salmon production)	The Norwegian Ministry of Trade, Industry and Fisheries (NFD), the Norwegian Directorate of Fisheries (NDF), The Norwegian Ministry of the Environment, the Norwegian Directorate of the Environment	The Norwegian Aquaculture Act **https://www.fiskeridir.no/English/Aquaculture/Aquaculture-Act**, with underlying regulations that relate to the technical standards of farms (to hinder escapes), monitoring and escapee re-capture strategies (when escapes have occurred), and obligations of the farmers to report escapees. Although not a law, the wild salmon quality standard **https://lovdata.no/dokument/SF/forskrift/2013-09-20-1109** is also used to present the status of wild salmon populations and there is a law offering some populations/fjords special protective status. There is also a law relating to removal of escapees from rivers where the numbers of escapees has been reported to be too high (this law is manifested through the OURO fish-farmer fund). The thresholds for the proportions of farmed escapees in rivers has been set at <4%, 4-10% and >10% for low, medium and high potential for genetic changes has been decided upon.	There are four major monitoring programs/elements. 1. The Norwegian national monitoring program for proportions of escapees in rivers (monitoring 200 rivers annually for proportions of farmed escapees) 2. Monitoring genetic status of wild salmon populations with molecular markers (how much introgression has occurred) 3. Risk assessment of Norwegian aquaculture that takes data from the escapee monitoring program and indicates where there are too many escapees in rivers in relation to the thresholds set (see laws and regulations), The official statistics for the numbers of farmed fish reported to escape **https://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Roemmingsstatistikk**	Farmers obliged to attempt recapture following escapes of fish. The NDF implement DNA tracing methods to identify the farm of origin in situations where unreported escapees are discovered in numbers. The NDF also has stand-by procedures for removal of escapees from rivers if not covered by the OURO program as and when needed. OURO program uses data from the escapee monitoring program, together with other available data (e.g., genetic status of populations) to target rivers in need of removal of farmed escapees on the spawning grounds. There are currently ~50 rivers where removal of escapees is paid for by this fund.	1. Quantification of the long-term biological consequences of introgression in native populations (demographic and life-history changes). 2. Validation of the established thresholds for low, moderate and high chances of further genetic introgression. 3. Regulations and knowledge for non-salmon escapees are lagging behind that for Atlantic salmon and are therefore in need of modification.
Portugal					
UK (Scotland)	Fish Health Inspectorate, Marine Scotland	Aquaculture and Fisheries (Scotland) Act 2013, Aquatic Animal Health (Scotland) Regulations 2009	Marine Scotland have a Technical Standard for Scottish Finfish Aquaculture which was produced to help prevent escapes as a result of technical failure and related issues.	Any suspected escape event must be reported to Marine Scotland. Within 28 days of the initial notification, a second notification must follow that provides final figures regarding the escape event. Notification of local district	Baseline quantification of introgression levels underway
USA	Environmental Protection Agency (EPA) or states authorized by EPA, National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS).	Clean Water Act - Section 402 establishes the National Pollutant Discharge Elimination System (NPDES) and authorizes EPA (or states authorized by EPA) to issue permits for point source discharges of pollutants into waters of the United States. Effluent Limitation Guidelines are established for Concentrated Aquatic Animal Production facilities, including marine net pen aquaculture producing 100,000 pounds or more of aquatic animals per year (40 CFR Part 451).More information can be found at: https://www.epa.gov/eg/concentrated-aquaticanimal-production-effluent-guidelines; http://www.ecfr.gov/cgi- bin/tex-tidx?SID=b32f065c3e56d423dbc1858e2a077818&mc=true&node=pt40.32.451&rgn=div5#sp40.32.451.b	Commercial fish farming occur primarily in the states of Maine and Washington and both these states are authorized by EPA to issue NPDES permits. Monitoring of escapes in these two states include: Maine - General Permit is the state-authorized NPDES permit: https://www.maine.gov/dep/water/wd/net-pen-aquaculture/MEG130000- 2014permit.pdf. The Department of Environmental Protection (DEP) requires that all reproductively viable Atlantic salmon placed in net pens must be of North American origin and transgenic salmonids are not authorized. Genetic evaluation information must be submitted to NMFS and USFWS. A marking plan, approved by NMFS and USFWS, is required to determine the origin of the fish. A Containment Management System (CMS) Plan is required that includes escape response, record keeping, and monitoring procedures to verify the effectiveness of escape control mechanisms. Email notification is required within 24 hours of a known escape of 24% or more of a cage population. Washington - Washington Department of Fish and Wildlife (WDFW) is the responsible agency for genetic interaction concerns. An escape prevention plan is required that includes how to minimize risk of escapement and tracking how many fish are lost. WDFW has authority to inspect at least on a n annual basis, facilities to determine conformity with respect to preventing and recapturing escapes. More information can be found at: https://apps.leg.wa.gov/wac/default.aspx?cite=220- 370 and https://app.leg.wa.gov/RCW/default.aspx?cite=77.125	Maine - Within 30 days of an escape, the CMS must be audited. Any time a CMS audit identifies deficiencies, a written report must contain a corrective action plan. Washington - Escape reporting and recapture plan must be included with each application for a marine finfish aquaculture permit. Reportable fish escapes must be reported within 24 hours of discover and the permittee must have a procedure for attempting to recapture escaped fish. More information can be found at: https://apps.leg.wa.gov/wac/default.aspx?cite=220-370-120	
China	none	none	none	none	none

Finfish	**Issue** **Sub-issue** **Description of the sub-issue**	Genetic and ecological issues Effects on wild species Impacts on the surrounding ecosystem (e.g. distribution and use of spawning areas for wild fish, impacts on marine mammals and birds)			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada	Species at Risk Act, Fisheries Act, Fisheries (General) Regulations		Appropriate siting	Full extent and consequences of both direct and indirect genetic interactions on wild salmon populations in Atlantic Canada. While tools and characterization of hybridization, introgression, F1 and F2 backcrosses in some salmon populations in Newfoundland and Labrador have been completed, the full extent of genetic impacts and specific impact on population dynamics has not been chacterized. Additionally, research is ongoing related to changes in demographics within populations. More information on the knowledge gaps generally and specifically for all ICES member countries farming salmon have been assessed and reported on through ICES advice to NASCO and OSPAR and as part of the work undertaken by the ICES WGAGFA.
Denmark	Ministry of Environment and Food for fish farms in locations more than 1 nm from the coast, and local municipalities for fish farms under 1 nm from the coast.	Legal Act for international nature protection No. 119 26.01.2017. Order for protection of nature and habitats No. 1240 24.10.2018	Only by the authorities - National water and habitat monitoring	Location	
Faroe Islands	Faroese Food and Veterinary Authority, environment agency	Regulation on disease preventive fish farming operation NO. 80 at 14.06.2019	No national monitoring of impact on wild species	Appropriate siting	There is still limited knowledge on impacts of fish farms on wild species.
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of finfish aquaculture in Ireland	See Escapes	See Escapes	See Escapes	See Escapes
Norway	Ref. Genetic issue		There is currently no specific monitoring of impacts on wild species (e.g. distribution and use of spawning areas) from farms in Norway.		There is still limited knowledge on impacts of fish farms on wild species and species diversity. Projects are initiated to study interactions between Atlantic salmon farming and wild populations of Atlantic cod
Portugal					
UK	Marine Scotland	See escapes	See escapes	See escapes	
USA	National Oceanic and Atmospheric Administration (NOAA) Also refer to Sensitive Habitat table	Marine Mammal Protection Act (MMPA) - allows for deterence but strictly prohibits lethal take. More information can be found at:http://www.NOAA Fisheries.noaa.gov/pr/laws/mmpa/; http://www.fisheries.noaa.gov/pr/interactions; http://www.fisheries.noaa.gov/ia/slider_stories/2016/08/mmpafinalrule.html	The Marine Mammal Authorization Program (MMAP), under the MMPA, requires that aquaculture facilities must annually categorize based on the relative frequency of incidental mortalities and serious injuries of marine mammals. Based on the category, there may be reporting requirements of all incidental mortalities or injuries of marine mammals within 48 hours of the occurrence. More information can be found at: https://www.fisheries.noaa.gov/national/marine-mammal- protection/marine-mammal-authorization-program. Washington - a permit may be denied based on the determination by the director of significant genetic, ecological or fish health risks of the proposed fish rearing program on naturally occurring fish and wildlife, their habitat or other existing fish rearing programs. More information can be found at: https://apps.leg.wa.gov/wac/default.aspx?cite=220-370-100	The MMPA allows deterrence of marine mammals from damaging gear or catch as long as the measures do not result in the death or serious injury of the marine mammal. NOAA Fisheries is currently developing national guidelines, under Section 101(a)(4) (B), for measures that can be used to safely deter marine mammals. More information can be found at: file:///C:/Users/Clete.Otoshi/Downloads/MMPA_2018 %20revised%20March%202019-508.pdf	
China	Fishery Law of the People's Republic of China Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China	Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 12: The natural spawning grounds, nursery grounds, feeding grounds and important migration passages of fish, shrimp, crabs, shellfish, and algae in the public owned water surface and tidal flats must be protected, and shall not be planned or used for aquaculture. Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 10: All the public owned and collectively-owned units engaged in aquaculture production using public owned water surfaces and tidal flats, shall apply to the local people's government at or above the county level for an aquaculture permit. Fishery Law of the People's Republic of China (2004) Article 37: The State maintains special protection of the rare and endangered aquatic wild animals such as white-flag dolphin to prevent them from extinction. Killing and injuring of important aquatic wild animals protected by the State is prohibited. Where it is necessary to catch such animals for purposes of scientific research, taming and propagation, exhi-bition or for other special purposes, the matter shall be dealt with in accordance with the provisions of the Law of the People's Republic of China on the Protection of Wildlife.	Fishery Law of the People's Republic of China (2004) Article 28: The administrative departments for fisheries under the people's governments at or above the county level shall work out overall plans and take measures to increase the fishery resources in the fishery waters under their jurisdiction. They may collect fees from the enterprises and individuals profiting from the use of such waters and devote the money thus collected to the increase and protection of the fishery resources. Measures for collecting such fees shall be formulated by the administrative department for fisheries together with the department of finance under the State Council and shall go into effect upon approval by the State Council.	Fishery Law of the People's Republic of China (2004) Article 29: The State protects the aquatic species and their living environment and establishes aquatic species protection zones in the main areas where aquatic species of high economic and hereditary breeding value grow and propagate. No unit or individual may engage in fishing in the protection zones without the approval of the administrative department for fisheries under the State Council.	Some research done on sensitive habitats, but not so much in relation to aquaculture

Annex 5: Overview of laws and regulatory standards and managing environmental impacts of marine shellfish aquaculture in countries contributed to WGEIA

Issue	**Sub issue**	**Description**
Effluents	Biodeposits under cages: Organic loading	Fall-off of cultured stock, faeces and pseudo faeces and suspended material, waste from cleaning
	Water column impacts: Nutrification	Change of phytoplankton through filter feeding, excretion of nitrogen, removal of nitrogen during harvest etc.
	Contaminants (Antifouling etc)	Fouling of non-culture species is an issue for shellfish farmers. Ways of dealing with the issue: chemicals, mechanical, placement in the intertidal zone, etc.
	Residues of medicine/drugs (Antibiotics)	Treatments during hatchery stages
Pathogens	Virus, bacteria, parasites	Risk of disease spread with transfers
Escapes	Genetic issues	Use of non-native species, movement of stocks
	Ecosystem issues	Interactions with native species, collection of spat
	Seed source	Collection of spat, source of seed (hatchery or wild)
Interaction with wild species	Protection of marine mammals and birds	Feeding grounds for shore birds, general disturbance, entanglement
Effects on sensitive habitat/spawning areas	Protection of essential fish habitat and sensitive ecosystems	Competition for space, shading, predator control mechanisms, disturbance during harvest

Shellfish	**Issue**	Effluents
	Sub-issue	Biodeposits under cages: Organic loading
	Description of the sub-issue	Fall-off of cultured stock, faeces and pseudo faeces and suspended material, waste from cleaning

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, provincial governments	Nationally: Fisheries Act, Aquaculture Activities Regulations, Pacific Aquaculture Regulations; Provincial aquaculture-related acts and regulations	No federal regulatory requirement for shellfish culture. Some provinces require benthic monitoring	Appropriate siting.	Considerable research has been conducted in Canada on the benthic impacts of organic biodeposition from shellfish culture and way to evaluate effects on infaunal communities
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017	sometimes sediment analyses		
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland; The Marine Institute is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAFM.	Monitoring set out under Licence conditions - Fisheries (amendment) Act 1997: Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy i.e., Water Framework Directive (WFD).	No monitoring of benthic conditions beneath shellfish culture operations. Under the WFD monitoring of seabed conditions (using macro-invertebrates) may be carried out in shared waterbodies.	Targeted research has determined that impacts of many shellfish culture operations are not impacting on seabed conditions. Activities associated with the culture (travel routes using vehicles) have been shown to be disturbing. In mitigation access routes are fixed and operators must not deviate from them.	
Norway	County Councils issuing aquaculture licences. During the licensing process environmental authorities are involved.	Regulated by the Aquaculture Act, but in order to issue aquaculture licenses it requires other permits under other legislations: -Food Act Regulations (Norwegian Food Safety Authority) -Harbour and Fairways Act (The Norwegian Coastal Administration) -Pollution Control Act (delegated to the County Governor) No decisions are required under the Nature Diversity Act, but the general principles must be included in the other decisions. Environmental considerations beyond the Pollution Control Act are regulated by the Aquaculture Act If the above are in order, permission is granted under the Aquaculture Act at the County Council.	No requirements for suspended culture systems. For sea ranching licenses baseline information on the benthic environment is required, including description of sediment and benthic flora and fauna.	Judgement to ensure carrying capacity is not exceeded.	Environmental impact assessment
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt)				
UK England	No single agency with direct responsibility for organic enrichment from shellfish farming. Indirect responsibilities: Environment Agency*, Natural England, Marine Management Organisation, Cefas Fish Health Inspectorate* (as regulatory authority under Defra), Local Planning Authority*. *=agency that may be required to undertake an EIA, HRA or WFD assessment.	Just general that also apply to aquaculture: The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC), Wildlife and Countryside Act 1981, The Marine Licensing (Application Fees) Regulations 2014 under the Marine and Coastal Access Act 2009, The Aquatic Animal Health (England and Wales) Regulations 2009, Town and Country Planning Act 1990 (England).	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area. Prior Environmental Impact Assessment (EIA). No current mechanism for subsequent monitoring other than site capacity and production self-reported and observed by Cefas Fish Health Inspectorate.	Judgement to ensure ecological carrying capacity is not exceeded.	Ecological carrying capacity (models)
UK Scotland	Marine Scotland, SNH	General regulations used for aquaculture (Aquaculture and Fisheries (Scotland) Act 2013).SNH are responsible for advising on potential benthic impacts during planning phase. Marine Scotland Science provide advice on carrying capacity for new planning applications based on a simple spreadsheet model.	No	Judgement to ensure ecological carrying capacity is not exceeded.	Carrying capacity models, lack of data
UK Northern Ireland	The Department of Agriculture Environment and Rural Affairs (DAERA)	DAERA is responsible for the granting of fish culture licences, shellfish fishery licences and marine fish fishery licences under the Fisheries Act (Northern Ireland) 1966. AFBI is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAERA. AFBI run the SMILE ecological carrying capacity model on behalf of DAERA. The following also apply The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC),.	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area. Some monitoring of sediments as part of new licences	Judgement to ensure ecological carrying capacity is not exceeded.	
USA	U.S. Army Corp of Engineers (USACE) or certain states issue regional permits	- Clean Water Act (CWA) Section 404: Discharges of dredged and/or fill material in association with the shellfish aquaculture operations including shellfish seeding, rearing, cultivating, transplanting, and harvesting, require authorization under Section 404 of CWA. The primary focus is on the potential effects of these activities on the chemical, physical, and biological integrity of waters of the United States. - Clean Water Act Section 401: requires that any person applying for a federal permit or license for an activity that may result in the discharge of pollutants into waters of the United States apply for a water quality certification that any discharge will comply with all water quality standards. - Rivers and Harbors Act Section 10: requires a permit from the USACE for construction of shellfish farms in the waters of the U.S. Under the consistency provision of the Coastal Zone Management Act (CZMA), 28 coastal and Great Lakes states may review the USACE's decision to grant a Section 10 permit if the project will have reasonably foreseeable effects on any coastal land or water use or natural resource in that state's coastal zone. Coastal states may require conditions on the permit, including water quality monitoring, to ensure any project off their respective coasts is consistent with their coastal management plans.	CWA and other state regulations implemented primarily at the permitting stage.	Spatial planning and siting farms	Habitat interactions
China	Fisheries governance authorities at all levels	- Fisheries Law of China (2004) Article 20 Aquacultural workers shall protect the ecological environment of the waters by scientifically defining the density of aquaculture, and through rational feeding and rational application of fertilizer and use of medicines, and contamination of the waters therefrom is not allowed. - Law of the People's Republic of China on the Prevention and Control of Water Pollution (2017) Article 57 Aquaculture activities should protect the ecological environment of the waters, scientifically determine the culture density, reasonably feed and use drugs to prevent pollution of the water environment.	- Fisheries Law of China (2004) Article 36: People's governments at all levels shall take measures to protect and improve the ecological environment of fishery waters and prevent pollution. The ecological environment of fishery waters shall be supervised and regulated and fishery pollution shall be investigated and handled in accordance with the relevant provisions of the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. - Some research projects include benthic survey.	- Fisheries Law of China (2004)Article 47: Anyone who damages the ecological environment of the fishery waters or causes fishery pollution shall be investigated for legal liability in accordance with the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. - Aquaculture spatial planning; Appropriate siting and culture density.	Considerable research has been conducted in China on the benthic impacts of organic biodeposition from shellfish culture, including the effects on infaunal communities and benthic conditions. MOM-B model was introduced from Norway and applied for evaluating aquaculture impact in Sanggou Bay, northern China (Zhang et al., 2013; Mao et al., 2010)

Shellfish	**Issue** **Sub-issue** **Description of the sub-issue**	Effluents Water column impacts: Nutrification Change of phytoplankton through filter feeding, excretion of nitrogen, removal of nitrogen during harvest etc.

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, and provinces	Fisheries Act		Appropriate siting, including bay scale considerations	The large scale effect of suspended culture on phytoplankton and shellfish production and ecological carrying capacity has been well studied in Canada. Work on evaluating filtration effects on zooplankton is beginning
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland; The Marine Institute is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAFM.	Monitoring may be set out under Licence conditions - Fisheries (amendment) Act 1997: Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy i.e., Water Framework Directive (WFD).	No specific monitoring of nutrient levels associated with shellfish culture operations. Under the WFD monitoring of physic-chemical (incl nutrients) parameters may be carried out in shared waterbodies.	No impacts on water quality from shellfish culture operations have been demonstrated in Ireland.	
Norway	No single agency with direct responsibility for water column interactions from shellfish farming.	None	No	Not an issue at current production level and management	Ecological interaction between suspension feeders and the environment at larger scale production.
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt)				
UK- England	No single agency with direct responsibility for water column interactions from shellfish farming. Indirect responsibilities: Environment Agency*, Natural England, Marine Management Organisation, Cefas Fish Health Inspectorate* (as regulatory authority under Defra), Local Planning Authority*. *=agency that may be required to undertake an EIA, HRA or WFD assessment.	Just general that also apply to aquaculture: The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC), Wildlife and Countryside Act 1981, The Marine Licensing (Application Fees) Regulations 2014 under the Marine and Coastal Access Act 2009, The Aquatic Animal Health (England and Wales) Regulations 2009, Town and Country Planning Act 1990 (England).	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area. Prior Environmental Impact Assessment (EIA). No current mechanism for subsequent monitoring other than site capacity and production self- reported and observed by Cefas Fish Health Inspectorate.	Judgement to ensure ecological carrying capacity is not exceeded.	Ecological carrying capacity (models)
UK Scotland	Marine Scotland Science, SEPA	General regulations used for aquaculture (Aquaculture and Fisheries (Scotland) Act 2013). Marine Scotland Science provide advice on carrying capacity for new planning applications based on a simple spreadsheet model. SEPA provide advice on impacts of water quality to shellfish producers	No	Judgement to ensure ecological carrying capacity is not exceeded.	Carrying capacity models, lack of data
UK Northern Ireland	The Department of Agriculture Environment and Rural Affairs (DAERA), NIEA	DAERA is responsible for the granting of fish culture licences, shellfish fishery licences and marine fish fishery licences under the Fisheries Act (Northern Ireland) 1966. AFBI is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAERA. AFBI run the SMILE ecological carrying capacity model on behalf of DAERA. The following also apply The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC),.	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area.	Judgement to ensure ecological carrying capacity is not exceeded.	
USA	U.S. Army Corp of Engineers (USACE)	- USACE Nationwide 48 Permit (NW48): and programmatic (regional) permits (as opposed to individual) are intended to streamline the authorization process for shellfish aquaculture activities that have minimal adverse effects on the environment. NWP 48 authorizes shellfish and has been modified to authorize expansion of existing commercial shellfish growing operations and new activities, with a 0.5 acre limit of disturbance to submerged aquatic vegetation beds. They have also removed the reporting requirement for certain on-going commercial shellfish aquaculture activities. https://www.swt.usace.army.mil/Portals/41/docs/missions/regulatory/NationwidePermits/Nationwand were used for ~97% of permits shellfish permits issued from 2012 to 2017. Districts may add conditions to nationwide permits or develop region-specific permits to address state or regional concerns. wide%20Permit%2048%20-%20Commercial%20Shellfish%20Aquaculture%20Activities.pdf?ver=2017-03-31-150710-693. - Regional regulations for Washington state (largest shellfish producer in U.S.) specify that temporary impacts to waters of the U.S. must not exceed six months and impacts must be identified in the pre-construction notification. - Clean Water Act (CWA) Section 401: Certification gives states reasonable assurance an applicant's project will comply with state water quality standards and other requirements for protecting aquatic resources. The Section 401 Certification can cover both construction and operation of a proposed project. - Clean Water Act Section 404: Discharges of dredged and/or fill material in association with the shellfish aquaculture operations including shellfish seeding, rearing, cultivating, transplanting, and harvesting, require authorization under Section 404 of CWA. The primary focus is on the potential effects of these activities on the chemical, physical, and biological integrity of waters of the United States. - Rivers and Harbors Act Section 10: requires a permit from the USACE for construction of shellfish farms in the waters of the U.S. Under the consistency provision of the Coastal Zone Management Act (CZMA), 28 coastal and Great Lakes states may review the USACE's decision to grant a Section 10 permit if the project will have reasonably foreseeable effects on any coastal land or water use or natural resource in that state's coastal zone. Coastal states may require conditions on the permit, including water quality monitoring, to ensure any project off their respective coasts is consistent with their coastal management plans.	Focus is on water quality monitoring by state agencies for contamination that would cause human health concerns rather than on negative water quality impacts of shellfish aquaculture.	Carrying capacity analysis has been used to aid decision-making for farm permitting and expansion. Carrying capacity models examine estuarine circulation and residence time, primary production, and bivalve clearance rates. The models are generally prepared by independent parties contributing to environmental review documentation for state agencies and the USACE.	Application and development of carrying capacity models; Estuarine residence time calculations
China	Marine Environment Monitoring Centre of the State Oceanic Administration (now of the Ministry of Ecology and Environment), local Ocean and Fisheries Bureau are the agencies responsible for monitoring water column	- Fisheries Law of China (2004) Article 20 Aquacultural workers shall protect the ecological environment of the waters by scientifically defining the density of aquaculture, and through rational feeding and rational application of fertilizer and use of medicines, and contamination of the waters therefrom is not allowed. - Law of the People's Republic of China on the Prevention and Control of Water Pollution (2017) Article 57 Aquaculture activities should protect the ecological environment of the waters, scientifically determine the culture density, reasonably feed and use drugs to prevent pollution of the water environment.	- Fisheries Law of China (2004) Article 36: People's governments at all levels shall take measures to protect and improve the ecological environment of fishery waters and prevent pollution. The ecological environment of fishery waters shall be supervised and regulated, and fishery pollution shall be investigated and handled in accordance with the relevant provisions of the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. Some research projects include water quality survey and long-term monitoring of aquaculture areas.	- Fisheries Law of China (2004) Article 47: Anyone who damages the ecological environment of the fishery waters or causes fishery pollution shall be investigated for legal liability in accordance with the Marine Environmental Protection Law of the People's Republic of China and the Water Pollution Prevention Law of the People's Republic of China. - Aquaculture spatial planning; Appropriate siting and culture density.	There are huge knowledge gap in interactions between shellfish and the water environment, in terms of the full range of feed source, the filtration particle size of respective shellfish species, the rate of excretion in relation to source of feed, etc.

Shellfish	**Issue**	Effluents
	Sub-issue	Contaminants (Antifouling etc)
	Description of the sub-issue	Fouling of non-culture species is an issue for shellfish farmers. Ways of dealing with the issue: chemicals, mechanical, placement in the intertidal zone, etc.

Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, Provincial governments	Fisheries Act, Aquaculture Activities Regulations, Pacific Aquaculture Regulations	Annual reporting requirements	None required	Assessment of risk completed for hydrated lime (DFO, 2016). Research completed on the benthic impacts from the use of high pressure water.
Denmark	not relevant				
Faroe Islands					
Germany					
Ireland	Operators	No specific legislation. Licence conditions under Fisheries (amendment) Act 1997 specifies, disposal of waste material (including fouling organisms) to be carried out in a proper manner.	Handling of invasive taxa must be carried out to ensure full removal from system. Monitoring of same may be required by licencing authority.	Measures to be undertaken for fouling by alien taxa are set out in the draft Marine Code of Practice prepared by Invasive Species Ireland and can be found on the web site at: http://invasivespeciesireland.com/.	
Norway	No direct requirements				
Portugal	No direct requirements				
UK- England	No direct requirements unless non-native fouling species.				
UK Scotland	No direct requirements				
UK Northern Ireland	No direct requirements				
USA	U.S. Environmental Protection Agency and state agencies	Pesticides and herbicides are regulated by the EPA Office of Pesticide Programs under the Federal Insecticide, Fungicide and Rodenticide Act. Additionally, under the Federal Food, Drug and Cosmetic Act, the EPA establishes “tolerances” (or maximum legally permissible levels) for pesticide residues in food. Such tolerances are important in the context of pesticide use in aquaculture industry, because farmers using chemical pesticides during production must adhere to any applicable tolerances set by the EPA in order to sell their products for human consumption. The Clean Water Act requires dischargers of pesticides obtain a valid permit from the EPA. Even if a pesticide’s label notes that it is approved for use in aquatic environments, discharges of said pesticide into waters of the United States requires an NPDES permit.	Special conditions of permitting	Siting analysis including models of pest distribution and salinity tolerance; Intertidal culture practices; Exposure to air drying and sunlight	Novel removal and control methods for biofouling. Control methods for biofouling on oysters and mussels include exposure to air, plastic wrap, and applications of dilute bleach, vinegar, acetic acid, and calcium hydroxide. These practices can account for up to 30% of the operational expenses in bivalve farming.
China	none	none	none	none	none

Shellfish	Issue Sub-issue Description of the sub-issue	Effluents Residues of medicine/drugs (Antibiotics) Treatments during hatchery stages			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	not relevant				
Denmark	not relevant				
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland	Use of chemicals in hatchery considered under Licence conditions - Fisheries (ammendment) Act 1997	no specific monitoring.		Extent of use of chemcials and discharge into marine environment by shellfish hatcheries?
Norway	Norwegian Food Safety Authority: Responsible for approval and control of the use of medicines in bivalve hatcheries. Norwegian Medicines Agency Norwegian Environment Agency	Food Law Animal Health Personnel Law Regulation for Diseases and placing on the market	There are no bivalve hatcheries in Norway. Bivalve fry is collected directly from the nature. There are a few scallop hatcheries. They do not use medicines. Therefore: there is no need for monitoring.	No medicines are used. Therefore, there are no environmental effects from medicines and thereby need for mitigation.	Not relevant.
Portugal	Veterinary authorities (DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt)				
UK- England	Veterinary Medicines Directorate: theoretically responsible for overseeing use of antibiotics, polyploid inducers and settlement inducers in bivalve hatcheries.	The Veterinary Medicines Regulations 2013 -appear to cover the 3 classes of treatment in molluscs. However, this regulation does not cover antibiotic use in microalgae production in hatcheries.	None. No inspection of treatment records nor residue testing.	Treatment use is considered extremely rare in England. What may take place is judged to be very minor in closed systems (so very limited discharge), in broodstock or juvenile stages (far removed from harvested product so no residue issue).	Data on industry practices to confirm assumptions of negligible risks.
UK Scotland	Unknown and very difficult to find information but - If medicinal products are to be used in hatcheries then this would be responsibility of SEPA and Veterinary Medicines Directorate.				
UK Northern Ireland	The Department of Agriculture Environment and Rural Affairs (DAERA) is responsible for overall licensing and management of aquaculture in Northern Ireland				
USA	Food and Drug Administration (FDA)	Federal Food, Drug, and Cosmetic Act - FDA regulates aquaculture drugs however there are no approved drugs for shellfish hatcheries. A list of approved drugs for aquaculture can be found at: https://www.fda.gov/animal-veterinary/aquaculture/approved-aquaculture-drugs.			Veterinary support and medicines for artificial spawning, genetic improvement, and germplasm conservation.
China	Ministry of Agriculture and Rural Affairs (MARA), Bureau of Fisheries (BF); Bureau of Veterinary (BV); National Medical Products Administration (NMPA)	BV and BF of MARA regulates drugs given to shellfish according to Veterinary Drugs Management Regulations (2004) - Section 6. Units using drugs will abide by the regulations on the safe use of veterinary drugs formulated by the administrative department for veterinary medicine of the State Council, and establish drug use records. MARA establishes the National Standard of "Discharge Requirements for Marine Aquaculture Effluents" and "Discharge Requirements for Freshwater Pond Farming Effluents"	For monitoring of veterinary drug residues, promote scientific, safe and rational use of drugs in the aquaculture, and ensure the safety of animal-derived food, MARA organized the "Animal and animal product veterinary drug residue monitoring plan" every year. Pollutant discharges allowed from the facility include MARA-approved standard.	With reference to international standards and European and American standards, the MARA has also formulated and issued China's "Maximum Limits for Veterinary Drug Residues in Foods of Animal Origin"	none

Shellfish	**Issue** **Sub-issue** **Description of the sub-issue**	Pathogens Virus, bacteria, parasites Risk of disease spread with transfers			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, Canadian Food Inspection Agency, Provinces	Health of Animals Act, Fisheries Act, Fisheries (General) Regulations, provincial laws and regulations		Use of movement control tools (e.g. Introduction and Transfer committees) to evaluate/prevent the introduction into areas.	While there has been considerable research undertaken, MSX still has an uncharacterized intermediate host which complicates assessments and mitigation tool selection.
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	The Marine Institute is the competent authority for the implementation in Ireland of Council Directive 2006/88/EC, which deals with the health of aquaculture animals and the prevention and control of certain aquatic diseases.	Council Directive 2006/88/EC	The Marine Institute implements a fish health monitoring programme which tests for diseases listed under Directive 2006/88/EC and other aquatic diseases of national importance. Exotic diseases are not currently found within the EU and must be eradicated. Non-exotic diseases are generally confined to certain parts of the Community, whilst other areas remain free. The approach to the eradication of non-exotic diseases, should they appear in Ireland, will be decided by the Competent Authority, on a case-by-case basis	Diseases outbreaks are manged on a case-by case basis.	
Norway	Norwegian Food Safety Authorities: responsible for monitoring health status of wild and farmed molluscs	Aquaculture Act, fully harmonized with 'EC Directive on Aquatic Animal Health 2006/88 Food Law Animal Health Personnel Law Regulation for Diseases and placing on the market	National surveillance program for bonamiosis and marteiliosis in mussels and flat oysters. Requirement for health control when transport between cultivation areas (from 2019)	Recognised disease freedom status. Screening programmes + disease control and eradication programmes. Import/export controls. Emergency measures when sudden high mortality or a pathogen is detected. Movement restrictions if pathogens detected.	Need for data on health status for entire coast (only selected sites monitored). Also need for more documentation on Marteilia refringens detected in mussels.
Portugal	Veterinary authorities (DGAV - Direção Geral de Alimentação e Veterinária; Directorate for Veterinary Services; www.dgv.min-agricultura.pt)				
UK England	Defra and Cefas Fish Health Inspectorate	EC Directive on Aquatic Animal Health 2006/88 transposed as The Aquatic Animal Health (England and Wales) Regulations 2009	Annual compliance inspections against conditions of authorisation + sampling on suspicion + compulsory reporting of mortality	Recognised disease freedom status. Screening programmes + disease control and eradication programmes. Import/export controls. Movement restrictions. Biosecurity Measures Plans at farm level.	Emerging diseases and impacts on wild species
UK Scotland	Fish Health Inspectorate, Marine Scotland	Aquatic Animal Health (Scotland) Regulations 2009	Fish health inspectors carry out inspection and testing. Farmers must keep a record of mortalities and movements of shellfish on and off their farm. The FHI carries out spot-checks on imports at points of entry and at destination points and also provides movement documents in order to meet the requirements for shellfish moving to other parts of the EU. If there waters are considered to be or may be infected by a notifiable disease, the Scottish Minsters may designate those waters in order to prevent the spread of disease	Recognised disease freedom status. Screening programmes + disease control and eradication programmes. Import/export controls. Movement restrictions. Biosecurity Measures Plans at farm level.	Emerging diseases and impacts on wild species
UK Northern Ireland	DAERA, Fish Health Inspectorate	Aquatic Animal health regulations (Northern Ireland) 2009	Fish health inspectors carry out inspection and testing. Farmers must keep a record of mortalities and movements of shellfish on and off their farm. The FHI carries out spot-checks on imports at points of entry and at destination points and also provides movement documents in order to meet the requirements for shellfish moving to other parts of the EU.	Recognised disease freedom status. Screening programmes + disease control and eradication programmes. Import/export controls. Movement restrictions. Biosecurity Measures Plans at farm level.	Emerging diseases and impacts on wild species
USA	State agencies and the National Shellfish Sanitation Program (NSSP) which is a federal/state cooperative program.	- The NSSP was created by the U.S. Food and Drug Administration (FDA) and adopted by the Interstate Shellfish Sanitation Conference (ISSC) to promote a uniform standard of sanitation in the harvesting, transporting, and processing of molluscan shellfish. To prevent shellfish from being grown in, and harvested from, water that doesn't meet water quality standards (including the presence of Vibros or noroviruses, the NSSP Model ordinance requires that states conduct sanitation surveys - States have regulations, for example, in Washington, Shellfish Import and Transfer permits are required and are intended to reduce risk associated with introducing and spreading shellfish disease agents and harmful aquatic pest organisms. - In Florida, shellfish imported from out-of-state sources for aquacultural purposes must be accompanied by documentation signed by a licensed veterinarian certifying that the stock does not show clinical signs of any disease pathogen which may pose a threat to natural shellfish populations. - On the other hand, in Louisiana, no additional law or administrative rule specific to the introduction of out-of-state oysters exists for Louisiana. However, LDWF does have established protocols in place to control the importation of oysters, oyster spat, seed, larvae, and/or genetic material (eggs and sperm) from outside of Louisiana. The protocol was developed specifically to prevent the introduction of invasive species and MSX oyster disease.			
China	Ministry of Agriculture and Rural Affairs (MARA), Bureau of Fisheries (BF); Bureau of Veterinary (BV);	- The Fisheries Law of China (2004) Article 17, The fry and fingerling of aquatic animals for import or export shall undergo quarantine in order to prevent the spread of diseases in or out of the territory. Quarantine shall be conducted in accordance with the quarantine laws and administrative regulations concerning the entry and exit animal and plant quarantine. Introduction of trans-genic fry and fingerling of aquatic animals shall undergo safety evaluation, the concrete administrative work shall be undertaken in accordance with the relevant regulations of the State Council. - Animal Epidemic Prevention Law of the People's Republic of China - Emergency Plan for Aquatic Animal Diseases	National Aquatic Technology Extension Station (NATES), under the BF of MARA, conducts the seeding quarantine in origin area action by which banning cross-regional transportation of aquatic seedlings carrying viruses.	Seeding quarantine in origin area action will help evaluate/prevent the introduction into areas.	

Shellfish	Issue Sub-issue Description of the sub-issue	Escapes Ge- netic issues Use of non-native species, movement of stocks			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, Provinces	Fisheries Act, Fisheries (General) Regulations, Pacific Aquaculture Regulations		Movement controls, as necessary	Currently much of the reared shellfish is from wild-collected spat stocks, so minimal risk to wild populations if from the same area. The extent of genetic structuring (including geographically) is not well characterized which would be needed to evaluate risk of escapes to wild "fish". As hatchery seed is developed, there will be more questions regarding genetic consequences
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland. The Marine Institute is the competent authority for the implementation in Ireland of Council Directive 2006/88/EC, which deals with the health of aquaculture animals and the prevention and control of certain aquatic diseases.	Monitoring may be set out under Licence conditions - Fisheries (amendment) Act 1997. Council Directive 2006/88/EC, which deals with the health of aquaculture animals and the prevention and control of certain aquatic diseases.	Under 2006/88/EC, all movement of shellfish (except those going to market) are subject to movement order and are thus recorded	No specific mitigation of mixing mussel species and minimising risk of hybridization. (Gosling *et al.*, 2008)	Effects (genetic and ecological) of movement of mussel stock from one part of country to another.
Norway	Directorate of Fisheries	Aquaculture Act use of local broodstock in Great scallop and European lobster sea ranching. No regulations for suspended cultures of shellfish.		Aquaculture of alien species is not allowed	
Portugal					
UK- England	Defra, Cefas Fish Health Inspectorate, GB Non- Native Species Secretariat, Natural England, Joint Nature Conservancy Council, Environment Agency, Inshore Fisheries and Conservation Agencies	The Use of Alien Species in Aquaculture Regulations transposed into The Aquatic Animal Health and Alien Species in Aquaculture (Amendment) (England and Wales) (EU Exit) Regulations 2018, Marine Strategy Framework Directive, Wildlife and Countryside Act 1981; EC Directive on Aquatic Animal Health 2006/88 transposed as Aquatic Animal Health (England and Wales) Regulations 2009 for stock movements	Annual compliance inspections against conditions of authorisation + removal of unauthorised species	Controls on introductions; triploidy	Unknown impacts of non-native species. Effective means of control. Regional genetic differences in native species.
UK - Scotland	Fish Health Inspectorate, Marine Scotland. SNH provide expert advice.	The Alien and Locally Absent Species in Aquaculture (Scotland) Regulations 2015 ("the 2015 Regulation") make provision for the enforcement of Council Regulation (EC) No 708/2007 ("the EU Regulation") and for the notification of both an intended movement of those species which are listed in Annex IV (with exceptions) of the EU Regulation and the translocation of a locally absent species within the United Kingdom for farming purposes. Though a non-native species, Pacific oyster has an exemption in this regulation since it is widespread and there is long established use in Scottish shellfish production.	Monitored for two years (or full generation cycle) after release into open facilities to assess if predicted effects were accurate. The monitoring period can also be extended if necessary.	Depends on the species and whether or not system is open or closed. Detailed in the planning process and licence application..	Unknown impacts of invasive and non-native species
UK - Northern Ireland	DAERA, Fish Health Inspectorate	Aquatic Animal health regulations (Northern Ireland) 2009	Fish health inspectors carry out inspection and testing. Farmers must keep a record of mortalities and movements of shellfish on and off their farm. The FHI carries out spot-checks on imports at points of entry and at destination points and also provides movement documents in order to meet the requirements for shellfish moving to other parts of the EU.	Recognised disease freedom status. Screening programmes + disease control and eradication programmes. Import/export controls. Movement restrictions. Biosecurity Measures Plans at farm level.	Emerging diseases and impacts on wild species
USA	State agencies and the National Shellfish Sanitation Program (NSSP) which is a federal/state cooperative program.	Shellfish Import Permits are required for the import of live shellfish for aquaculture, research or display purposes and other uses. Shellfish which are market ready and do not come in contact with the state waters do not require a permit. Consistent with state law, permits will include conditions to ensure that disease, pests and invasive species do not enter the State's waters. Actions found to be in violation of these conditions, will result in modification or revoking of the permit. Transfer Permits are required for the transfer of shellfish, shellfish aquaculture products (including oyster seed, cultch and shell), aquaculture equipment (including aquaculture vehicles and vessels) and any marine organism adversely affecting shellfish. Consistent with state law, Transfer Permits include conditions that eliminate or reduce the risk of transferring marine pests, such as oyster drills, from one body of water to another, and require documentation of transfer vehicles, cleaning and disposal methods and other preventative measures.			
China	Bureau of Import and Export at national and local levels; National Marine Environment Monitoring Center (NMEMC), Ministry of Ecology and Environment	Law on Quarantine of Import/Export Animal and Plant of the People's Republic of China. Regulations on Management of Alien Species is now being drafted. Bulletin of China Marine Ecological Environment Status, published by NMEMC every year, reports on invasive species in 15 marine protected areas.	Only certain regulations on quarantine or/and observations of import animals and plants, before release	Control on introduction, for pathogens carried by the introduced species; no movement control domestically	China has introduced more than 140 aquatic species for aquaculture or for remediation of coastal wetlands. Impacts of certain species, such as common cordgrass *Spartina anglica* and smooth cordgrass *S. alterniflora* has been well studied, yet impact of most of other non- native species has not been systematically studied. China also lacks monitoring and effective means of control on invasive species.

Shellfish	Issue Sub-issue Description of the sub-issue	Escapes Eco- system issues Interactions with native species, collection of spat			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, Provinces	Fisheries Act, Fisheries (General) Regulations, Pacific Aquaculture Regulations		Movement controls, as necessary	Currently much of the reared shellfish is from wild-collected spat stocks, so minimal risk to wild populations if from the same area. The extent of genetic structuring (including geographically) is not well characterized which would be needed to evaluate risk of escapes to wild "fish". As hatchery seed is developed, there will be more questions regarding genetic consequences
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland; The Marine Institute is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAFM.	Shellfish Licence governed by Fisheries (amendment) Act 1997:	Monitoring the occurrence of C. gigas in Irish waters. No specific monitoring of shellfish naturalisation occurs in Ireland. A number of Academic studies have been carried out to determine factors governing c gigas naturalisation.	Management recommendation have resulted from academic studies, e.g., use of triploid oysters in areas where risk of naturalisation is considered high. Monitoring of interactions of wild-C. gigas oysters and native oysters indicate that harm is not likely, yet further work is required.	Interactions with native species and clear definition of 'harm'.
Norway	Directorate of Fisheries	Pacific oyster as an invasive species will be regulated according to the Aquaculture act. Juridical conditions are pending.	Mapping and monitoring of spreading of Pacific oyster	Controls on introductions. Removal of oyster beds in conflict areas.	Unknown impacts of non-native species. Effective means of control
Portugal					
UK England	Defra, Cefas Fish Health Inspectorate, GB Non-Native Species Secretariat, Natural England, Joint Nature Conservancy Council, Environment Agency, Inshore Fisheries and Conservation Agencies	The Use of Alien Species in Aquaculture Regulations transposed into The Aquatic Animal Health and Alien Species in Aquaculture (Amendment) (England and Wales) (EU Exit) Regulations 2018, Marine Strategy Framework Directive, Wildlife and Countryside Act 1981; EC Directive on Aquatic Animal Health 2006/88 transposed as Aquatic Animal Health (England and Wales) Regulations 2009 for stock movements	Annual compliance inspections against conditions of authorisation + removal of unauthorised species	Controls on introductions; triploidy	Unknown impacts of non-native species. Effective means of control. Regional genetic differences in native species.
UK Scotland	Fish Health Inspectorate, Marine Scotland, Scottish Natural Heritage (SNH)	The Aquatic Animal Health (Scotland) Regulations 2009, requires the authorisation of all aquaculture businesses before development. To obtain authorisation, prospective producers must meet a number of conditions, including species containment If shellfish farms wish to use non-native or locally absent species (e.g. Pacific oyster) then the FHI assess the infrastructure and equipment, operational and biosecurity practices at the farm and the determine if the shellfish are likely to be confined. If needed, the FHI will seek advice from Scottish Natural Heritage (SNH). Producers must prepare a Biosecurity Measures Plan (BMP), FHI can offer assistance with this. In addition to fulfilling the requirements of the Aquatic Animal Health regulations, during the planning process, shellfish farmers will also have to fulfill these requirements and show good biosecurity and operational practices will take place at Pacific oyster sites.		Controls on introduction through the planning and licensing process.	
UK Northern Ireland	DAERA is responsible for the granting of fish culture licences, shellfish fishery licences and marine fish fishery licences under the Fisheries Act (Northern Ireland) 1966. AFBI is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAERA.	Fisheries Act (Northern Ireland) 1966	No specific monitoring	Management recommendations include the use of triploid oysters.	
USA	- Army Corp of Engineers (USACE) - National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS) - US Fish and Wildlife Service (USFWS) - State, local and tribal organizations	- NW48 (see description in wat_col tab): to prevent introduction of aquatic nuisance species, no material that has been taken from a different waterbody may be reused in the current project area, unless it has been treated in accordance with the applicable regional aquatic nuisance species management plan. - National Environmental Policy Act: USACE generally must evaluate the potential environmental effects of projects proposed. - Endangered Species Act (ESA): requires that federal permitting agencies consult with NMFS and USFWS if threatened or endangered species or their critical habitat may be affected. - Recently, the states of Florida and Rhode Island began requiring shellfish hatcheries to treat effluent water to prevent the release of feed microalgae because, as a precaution, all microalgal feed species are considered to be non-native.			
China	Fisheries governance authority at all levels	- Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 24 For the capture of seedlings or fishery-banned broodstock with eggs of important economic aquatic species, such as eels, shad, Chinese mitten crabs, red seabream, grouper etc, for aquaculture or other special needs, approval must be obtained from the fishery administrative department of the State Council or the fishery administrative department of the people's government of a province, autonomous region, or municipality, and a special license must be obtained before fishing within the designated area and time limit, and according to the approved allowable catch. The authority to approve the fishing of other aquatic animal seeds of important economic value shall be prescribed by the fishery administrative department of the people's government of the province, autonomous region, or municipality. - Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 25 It is forbidden to catch Chinese prawn seedlings and spring broodstock. For the aquaculture of Chinese prawns, the broodstock should be raised by the aquaculture unit within a time limit, and the time limit and management measures shall be formulated by the fishery administrative department of the State Council.	Monitoring and enforcement by fishery administration		

Shellfish	**Primary issue** **Sub-issue** **Description of the sub-issue**	Escapes Seed source Collection of spat, source of seed (hatchery or wild)			
Country	Responsible agencies	Laws and regulations	Monitoring	Mitigation	Knowledge Gap
Canada	Fisheries and Oceans Canada, Provinces	Fisheries Act, Fisheries (General) Regulations, Pacific Aquaculture Regulations			Risk of escapes to wild "fish" poorly understood, especially with respect to genetic consequences; direct impacts due to establishment of non-native species understood but not those on receiving ecosystem
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland; The Marine Institute is responsible for providing scientific advice in relation to aquaculture operations and practices and reporting to DAFM. Bord Iascaigh Mhara (BM) advisory body for aquaculture development.	Seed sources must be identified during applications process. Licence conditions under Fisheries (amendment) Act 1997 may specify the source and type of seed to be used in operations. Wildlife legislation may require certain risk analysis be conducted on the source and type of seed used.	Monitoring may be specified in licences.	Triploid seed (oysters) may be specified to be used if the risk of reproduction and recruitment identified as high. Timing of wild (mussel) seed collection constrained to avoid overlap with other sensitivities, e.g., breeding birds. Wild seed collection may be constrained by availability and bird requirements.	
Norway	Norwegian Food Safety Authorities: responsible for monitoring health status of imported animals for aquaculture	Food Act, through regulations of transportation, trade and import of aquaculture animals. In sea ranching, Aquaculture Act: documentation on source of seed	In sea ranching: documentation on source of seed	Not an issue	Unexplained interannual variation in spat/seed settlement/availability
Portugal					
UK England	Inshore Fisheries and Conservation Agencies, Marine Management Organisation	Sea Fisheries (Shellfish) Act 1967	Fishery enforcement and landings monitoring	Stock assessment for seed shellfish resources (to ensure sufficient left for wildlife)	Unexplained interannual variation in spat/seed settlement/availability
UK Scotland	Marine Scotland, local planning authorities	Aquaculture and Fisheries (Scotland) Act 2013, Sea Fisheries (Shellfish) Amendment (Scotland) Act 2000		Not an issue	Unexplained interannual variation in spat/seed settlement/availability. Uncertainties about future seed supply via hatcheries - trying to establish mussel
UK Northern Ireland	DAERA is responsible for the granting of fish culture licences, shellfish fishery licences and marine fish fishery licences under the Fisheries Act (Northern Ireland) 1966. AFBI is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAERA. AFBI run the SMILE ecological carrying capacity model on behalf of DAERA. The following also apply The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC),.	Fisheries Act (Northern Ireland) 1966			
USA	See Pathogens and Escape_gen tabs				
China	Fisheries governance authority at all levels	- Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 24 For the capture of seedlings or fishery-banned broodstock with eggs of important economic aquatic species, such as eels, shad, Chinese mitten crabs, red seabream, grouper etc, for aquaculture or other special needs, approval must be obtained from the fishery administrative department of the State Council or the fishery administrative department of the people's government of a province, autonomous region, or municipality, and a special license must be obtained before fishing within the designated area and time limit, and according to the approved allowable catch. The authority to approve the fishing of other aquatic animal seeds of important economic value shall be prescribed by the fishery administrative department of the people's government of the province, autonomous region, or municipality. - Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 25 It is forbidden to catch Chinese prawn seedlings and spring broodstock. For the aquaculture of Chinese prawns, the broodstock should be raised by the aquaculture unit within a time limit, and the time limit and management measures shall be formulated by the fishery administrative department of the State Council.	Monitoring and enforcement by fishery administration		

Shellfish	**Issue** **Sub-issue** **Description of the sub-issue**	Interaction with wild species Protection of marine mammals and birds Feeding grounds for shore birds, general disturbance, entanglement			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Environment Canada	Migratory Birds Convention Act (MBCA), Species at Risk Act (SARA)			Interactions of shellfish farming with wildlife
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland; The Marine Institute (MI) provides scientific advice on a range of marine environment and aquaculture matters and in the case of applications which require Appropriate Assessment (AA) under EU Birds and Habitats Directives, the MI prepares scientific reports. Management of conservation sites (SACs, SPAs, and setting of objectives is carried out	The Fisheries (Amendment) Act 1997 and its associated Regulations set out the framework for the processing of Aquaculture licensing operations. European Communities (Birds and Natural Habitats) Regulations 2011 (S.I. No. 477 Of 2011). Birds Directive: Directive 74/409/EEC on the conservation of wild birds. Habitats Directive: Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.	Site specific monitoring conditions maybe imposed on licences to monitor specific measures enacted to mitigate against impact on conservation features including habitats and species. Measures taken to ensure no disturbance to mammals and/or birds. Article 12 and 17 monitoring of the EU regulations which require reporting every 6 years on the conservation status of features and a commentary on the potential threats (including aquaculture operations).	A range of mitigation measures may apply to licences that are designed to minimise impacts on conservation features.	Cumulative effects when assessing impacts. Detailed conservation objectives to identify specific habitat and species sensitivities.
Norway	County councils issuing aquaculture licences. During the licensing process environmental authorities are involved.	Regulated by the Aquaculture Act, but in order to issue aquaculture licenses it requires other permits under other legislations: -Food Act Regulations (Norwegian Food Safety Authority) -Harbour and Fairways Act (The Norwegian Coastal Administration) -Pollution Control Act (delegated to the County Governor) No decisions are required under the Nature Diversity Act, but the general principles must be included in the other decisions. Environmental considerations beyond the Pollution Control Act are regulated by the Aquaculture Act	County Council	None	Interactions of shellfish farming with wildlife
Portugal					
UK England	No single agency with direct responsibility for general wildlife interactions with shellfish farming. Indirect responsibilities: Environment Agency*, Natural England, Marine Management Organisation, Cefas Fish Health Inspectorate* (as regulatory authority under Defra), Local Planning Authority*. *=agency that may be required to undertake an EIA, HRA or WFD assessment.	Just general that also apply to aquaculture: The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC), Wildlife and Countryside Act 1981, The Marine Licensing (Application Fees) Regulations 2014 under the Marine and Coastal Access Act 2009, The Aquatic Animal Health (England and Wales) Regulations 2009, Town and Country Planning Act 1990 (England).	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area. Prior Environmental Impact Assessment (EIA). No current mechanism for subsequent monitoring other than site capacity and production self-reported and observed by Cefas Fish Health Inspectorate.	Bird counts/surveys	Interactions of shellfish farming with wildlife
UK Scotland	SNH, Local planning authorities	During planning application, SNH will identify potential risks to other wildlife. General aquaculture regulations are also relevant (Aquaculture and Fisheries (Scotland) Act 2013 and Aquatic Animal Health (Scotland) Regulations 2009). The Sea Fisheries (Shellfish) Amendment (Scotland) Act 2000 considers interactions with fisheries.	Assessment during planning phase		Interactions of shellfish farming with wildlife
UK Northern Ireland	The Department of Agriculture Environment and Rural Affairs (DAERA)	DAERA is responsible for the granting of fish culture licences, shellfish fishery licences and marine fish fishery licences under the Fisheries Act (Northern Ireland) 1966. AFBI is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAERA. AFBI run the SMILE ecological carrying capacity model on behalf of DAERA. The following also apply The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC),.	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area	A range of mitigation measures may apply to licences	
USA	- Army Corp of Engineers (USACE) - National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS) - US Fish and Wildlife Service (USFWS) - State, local and tribal organizations	- NW48 (see description in wat_col tab): no activity may substantially disrupt the necessary life cycle movements of those species of aquatic life indigenous to the waterbody. Activities in waters that serve as breeding areas for migratory birds must be avoided to the maximum extent practicable. - National Environmental Policy Act: USACE generally must evaluate the potential environmental effects of projects proposed. - Endangered Species Act (ESA): requires that federal permitting agencies consult with NMFS and USFWS if threatened or endangered species or their critical habitat may be affected. - Essential Fish Habitat (EFH) under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA): eel grass is designated as EFH in certain regions and MSFCMA requires federal permitting agencies consult with NMFS regarding effects on EFH. - Migratory Bird Treaty Act (MBTA): The USFWS has responsibility of conserving migratory birds through protection, restoration, and management. - Marine Mammal Protection Act (MMPA): NMFS has responsibility and the MMPA prohibits harm or harassment (“take”) of marine mammals, unless restrictive permits are obtained.	- For Washington state, a maintenance and monitoring plan commensurate with the impacts to disturbed native plant vegetation, may be required.	- Section 7 of the Endangered Species Act requires the Corps to consult with NMFS and/or the USFWS on development of appropriate terms and conditions to avoid, minimize, or compensate for the adverse impacts. - NW48: mitigation in all its forms (avoiding, minimizing, rectifying, reducing, or compensating for resource losses) will be required to the extent necessary to ensure that the individual and cumulative adverse environmental effects are no more than minimal. - For Washington state, the permittee must revegetate disturbed areas with native plant species sufficient in number, spacing, and diversity to restore affected functions.	
China	none	none	none	none	very limited study in all aspects

Shellfish	**Issue**	Effects on sensitive habitat/spawning areas			
	Sub-issue	Protection of essential fish habitat and sensitive ecosystems			
	Description of the sub-issue	Competition for space, shading, predator control mechanisms, disturbance during harvest			
Country	**Responsible agencies**	**Laws and regulations**	**Monitoring**	**Mitigation**	**Knowledge Gap**
Canada	Fisheries and Oceans Canada, Provincial governments	Fisheries Act, provincial laws and regulations	some monitoring of eelgrass undertaken in some locations	Assessed during siting process	Significant research has been completed regarding shellfish aquaculture impacts and effects on eelgrass.
Denmark	Danish Fisheries Agency and Ministry of Environment	Production permission is granted under Fisheries law no. 764 of 19. June 2017 and for production in the water Colum after order no 1387 from 3.12.2017, and for permission for production at the sea bed order no. 764 19.06.2017, and Legal Act for international nature protection No. 119 26.01.2017			
Faroe Islands					
Germany					
Ireland	Department of Agriculture Food and Marine (DAFM) is responsible the overall licencing and management of shellfish aquaculture in Ireland; The Marine Institute (MI) provides scientific advice on a range of marine environment and aquaculture matters and in the case of applications which require Appropriate Assessment (AA) under EU Birds and Habitats Directives, the MI prepares scientific reports. Management of conservation sites (SACs, SPAs, and setting of objectives is carried out	The Fisheries (Amendment) Act 1997 and its associated Regulations set out the framework for the processing of Aquaculture licensing operations. European Communities (Birds and Natural Habitats) Regulations 2011 (S.I. No. 477 Of 2011). Birds Directive: Directive 74/409/EEC on the conservation of wild birds. Habitats Directive: Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.	Site specific monitoring conditions may be imposed on licences to monitor specific measures enacted to mitigate against impact on conservation features. Article 12 and 17 monitoring of the EU regulations which require reporting every 6 years on the conservation status of features and a commentary on the potential threats (including aquaculture operations).	A range of mitigation measures may apply to licences that are designed to minimise impacts on conservation features.	Cumulative effects when assessing impacts. Detailed conservation objectives to identify specific habitat and species sensitivities.
Norway	Municipality is responsible for aquaculture planning, allocation of space for fish farming (competition for space), County council is responsible for environmental impact of shellfish farming (disturbance during harvest)	Building and planning act and aquaculture planning, Aquaculture act	Inspection from responsible authorities (Directorate of fisheries, Norwegian Food Safety Authority)	None	Comprehensive and modern spacial planning of shellfish aquaculture
Portugal	APA - Agência Portuguesa do Ambiente (Portuguese Environment Agency; www.apambiente.pt)				
UK England	No single agency with direct responsibility for general wildlife interactions with shellfish farming. Indirect responsibilities: Environment Agency*, Natural England, Marine Management Organisation, Cefas Fish Health Inspectorate* (as regulatory authority under Defra), Local Planning Authority*. *=agency that may be required to undertake an EIA, HRA or WFD assessment.	Just general that also apply to aquaculture: The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC), Wildlife and Countryside Act 1981, The Marine Licensing (Application Fees) Regulations 2014 under the Marine and Coastal Access Act 2009, The Aquatic Animal Health (England and Wales) Regulations 2009, Town and Country Planning Act 1990 (England).	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area. Prior Environmental Impact Assessment (EIA). No current mechanism for subsequent monitoring other than site capacity and production self-reported and observed by Cefas Fish Health Inspectorate.		Interactions of shellfish farming with wildlife
UK Scotland	SNH, Local planning authorities	During planning application, SNH will identify potential risks to sensitive habitats (or priority marine features within MPAs). SNH will also advise if an Appropriate Assessment (AA) is required. General aquaculture regulations are also relevant (Aquaculture and Fisheries (Scotland) Act 2013 and Aquatic Animal Health (Scotland) Regulations 2009).	Assessment during planning phase		Designation and management of MPAs. Interactions of shellfish farming with wildlife
UK Northern Ireland	The Department of Agriculture Environment and Rural Affairs (DAERA)	DAERA is responsible for the granting of fish culture licences, shellfish fishery licences and marine fish fishery licences under the Fisheries Act (Northern Ireland) 1966. AFBI is responsible for providing scientific advice in relation to aquaculture operations and practices to and reporting to DAERA. AFBI run the SMILE ecological carrying capacity model on behalf of DAERA. The following also apply The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, The Conservation of Habitats and Species Regulations 2017, Birds Directive (2009/147/EC),.	Prior Habitats Regulations Assessment (HRA) if inside or potentially impacts on Special Area of Conservation or Special Protected Area	A range of mitigation measures may apply to licences	
USA	- Army Corp of Engineers (USACE) - National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS) - US Fish and Wildlife Service (USFWS) - State, local and tribal organizations	- NW48 (see description in wat_col tab): certain districts have added conditions prohibiting shellfish activity within submerged aquatic vegetation beds or saltmarshes. -Endangered Species Act (ESA) - requires that federal permitting agencies consult with NMFS and USFWS if threatened or endangered species or their critical habitat may be affected. - Essential Fish Habitat (EFH) under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) - eel grass is designated as EFH in certain regions and MSFCMA requires federal permitting agencies consult with NMFS regarding effects on Essential Fish Habitat. - Rivers and Harbors Act Section 10: requires authorization from the Secretary of the Army, acting through the Corps of Engineers, for the construction of any structure in or over any navigable water of the United States.	- While there are no requirements to establish monitoring under MSFCMA or ESA, recommendations may be provided depending upon the specific project. - In Washington state, If the USACE determines the project will result In temporary impacts of submerged aquatic vegetation (SAV) that are more than minimal, a monitoring plan must be submitted. If recovery is not achieved by the end of the monitoring period, contingencies must be implemented, and additional monitoring will be required.	- Section 7 of the Endangered Species Act requires the USACE to consult with NMFS and/or the FWS on development of appropriate terms and conditions to avoid, minimize, or compensate for the adverse impacts. - NW48: mitigation in all its forms (avoiding, minimizing, rectifying, reducing, or compensating for resource losses) will be required to the extent necessary to ensure that the individual and cumulative adverse environmental effects are no more than minimal.	
China	- Fishery Law of the People's Republic of China - Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China	- Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 12: The natural spawning grounds, nursery grounds, feeding grounds and important migration passages of fish, shrimp, crabs, shellfish, and algae in the public owned water surface and tidal flats must be protected, and shall not be planned or used for aquaculture. - Detailed Rules for the Implementation of the Fishery Law of the People's Republic of China Article 10: All the public owned and collective-owned units engaged in aquaculture production using public owned water surfaces and tidal flats, shall apply to the local people's government at or above the county level for an aquaculture permit. - Fishery Law of the People's Republic of China (2004) Article 37: The State maintains special protection of the rare and endangered aquatic wild animals such as white-flag dolphin to prevent them from extinction. Killing and attacking of important aquatic wild animals protected by the State is prohibited. Where it is necessary to catch such animals for purposes of scientific research, taming and propagation, exhibition or for other special purposes, the matter shall be dealt with in accordance with the provisions of the Law of the People's Republic of China on the Protection of Wildlife.	Fishery Law of the People's Republic of China (2004) Article 28: The administrative departments for fisheries under the people's governments at or above the county level shall work out overall plans and take measures to increase the fishery resources in the fishery waters under their jurisdiction. They may collect fees from the enterprises and individuals profiting from the use of such waters and devote the money thus collected to the increase and protection of the fishery resources. Measures for collecting such fees shall be formulated by the administrative department for fisheries together with the department of finance under the State Council and shall go into effect upon approval by the State Council.	Fishery Law of the People's Republic of China (2004) Article 29: The State protects the aquatic species and their living environment and establishes aquatic species protection zones in the main areas where aquatic species of high economic and hereditary breeding value grow and propagate. No unit or individual may engage in fishing in the protection zones without the approval of the administrative department for fisheries under the State Council.	Some research done on sensitive habitats, but not so much in relation to aquaculture