OSPAR
COMMISSION

Assessment of Impacts of Mariculture

Biodiversity Series

2009

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

Convention OSPAR

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998.
La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

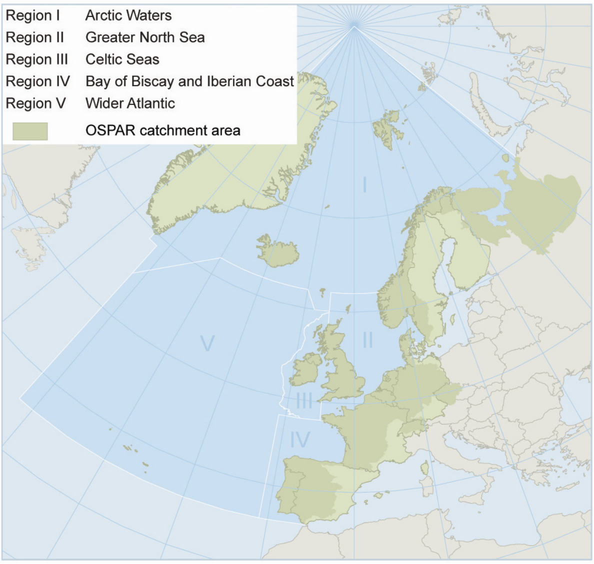

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Photo cover page: Mariculture in the Atlantic©Audrey Baconnais-Rosez

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Executive summary

Mariculture has grown rapidly in the OSPAR area

Mariculture of fish and shellfish has increased markedly in OSPAR coastal waters over the last 20 years. In 2006, almost 1.5 million tonnes of farmed fish and shellfish were produced in the OSPAR area representing 4.2% of the world's mariculture production. Since 1998 the production of finfish in the OSPAR area has increased by 57%, mainly due to increased production in Region I (Arctic Waters) and Region II (Greater North Sea). Shellfish farming is most intensive Regions II and IV (Bay of Biscay and Iberian Coast). It can be expected that fish farming in the OSPAR maritime area will continue to increase.

Fish and shellfish farming has a wide range of potential environmental impacts

Mariculture gives rise to a number of concerns: the placement of fish farms within sensitive marine areas, the spread of invasive species and dependency on industrial catches of wild fish to feed fish in mariculture. Local effects include eutrophication from feeds and effluents, release of antifouling chemicals and antibiotics, displacement of bird and seal populations by scaring devices to discourage predation of farmed fish and impacts from the harvesting of shellfish and from seed collection for mussel farming.

Fish escaping from farms may compete with wild stocks for spawning grounds in freshwater habitats. In addition, the transfer of parasites and diseases and genetic interaction between escaped farmed fish and wild stocks is a concern.

The environmental impacts of mariculture activities are very site-specific

OSPAR previously acknowledged that the mariculture industry is very diverse, its impacts are mostly site-specific, regulation and control will therefore always need to be focused on a case-by-case approach, and a substantial amount of general guidance is available to give the background to these case-by-case decisions. On that basis, OSPAR concluded at that time that there was no need for development of additional programmes and measures at an OSPAR level.

This assessment reaffirms this conclusion for the time being. There are, however, a number of far-field impacts identified, namely, the introduction of alien species, impacts of sea lice, ecological and genetic impacts of escaped fish and increased demand for industrial fisheries products which should be periodically reviewed at an OSPAR / regional sea wide level. Information should continue to be exchanged on these issues. In addition, should mariculture activities move offshore and develop in combination with other activities; methods for assessing the cumulative impacts of such developments will be required.

OSPAR recommends Best Environmental Practice

OSPAR recommends Best Environmental Practice for the reduction of inputs of potentially toxic chemicals from aquaculture. In addition, measures under the Eutrophication-, Hazardous Substances- and the Biological Diversity and Ecosystem Strategy monitor, assess and regulate the impacts of mariculture. Different European Commission measures address the pollution and biodiversity impacts of mariculture, including the use of alien and locally absent species in aquaculture.

Even though national legislation does not fully implement the requirements of OSPAR, the intention of the Recommendation on chemicals from aquaculture seems to be fulfilled by national or EU legislation. The increased use of vaccines has significantly reduced the use of antibiotics in mariculture since the 1980s and this has been maintained over the past 10 years. Tributyltin in antifouling agents for mariculture equipment has been substituted by copper-based substances; however, concern has been raised due to the increasing release of copper mainly in Region I and II. Norway has reported increased mariculture related nutrient inputs in Region I, although, in Scotland, an assessment of the effect of nutrients from mariculture in Scottish Sea lochs concluded it was not a problem.

Improved knowledge of the effects of mariculture is needed

An expansion of mariculture may decrease overall pressure on some fish stocks. Conversely, expansion, with a focus on carnivorous fish, may increase the demand for feed derived from industrial fishing. The degree of impact, both positive and negative, of mariculture on wild fish stocks in the OSPAR area is unclear and improved knowledge of the interactions between farming different species and wild fish stocks is needed.

Lice from farmed salmon have been suggested as a cause of the decline of wild salmon and sea trout in the vicinity of salmon farms. The effects of chemicals and therapeutants on benthos and biodiversity, including the reduction of their use through improved husbandry practice and the use of vaccines for disease and parasite control, warrant further research.

The contribution of farmed and ranched salmon to national catches in the North-East Atlantic Area in 2007 was generally low (<2% in most countries) and is similar to the values that have been reported previously by ICES. The occurrence of such fish is usually ignored in assessments of the status of national stocks. However, in Norway farmed salmon continue to form a large proportion of the catch in coastal (29% in 2007), fjordic (30% in 2007) and rod fisheries (9% in 2007), and the average proportion of farmed salmon in the spawning stocks in 2007 was 14%.

The main risk from escaped fish could be due to displacement of wild fish, loss of production, and direct genetic intrusion. The genetic impact of farms escapees on biodiversity, including the ability of wild populations to recover from the introgression of farmed genes, requires further research.

Offshore mariculture has the potential to grow

Offshore mariculture, on its own or in combination with other offshore technologies such as wind farms, has the potential for growth. Improvements in cage technology will help reduce the large number of cultured fish escapees.

Climate change will require adaptation of mariculture management approaches

Impact from the expected growth of mariculture requires continued monitoring and assessment, including effects on ecosystem status. The exchange of information on impacts at the regional level and, where necessary, the development of coordinated management frameworks should continue. Sea temperature rises has the potential to modify the area where introduced species can become established. For example, Pacific oysters have established wild populations in France and as far north as Denmark and Sweden, areas previously considered too cold for viable reproduction. Displacement of indigenous prey species has resulted in increased mortality and reduced breeding success of some shorebirds.

Récapitulatif

Croissance rapide de la mariculture dans la zone OSPAR

La mariculture du poisson, des mollusques et crustacés s'est accrue notablement dans les eaux côtières OSPAR au cours des vingt dernières années. En 2006, l'élevage de poisson et de mollusques et crustacés a produit presque 1,5 millions de tonnes dans la zone OSPAR, ce qui représente 4,2% de la production maricole mondiale. Depuis 1998 la production de poisson à nageoires dans la zone OSPAR a augmenté de 57% ce qui est dû essentiellement à l'augmentation de la production dans les Régions I (eaux arctiques) et II (mer du Nord au sens large). La conchyliculture la plus intensive est réalisée dans les Régions II (golfe de Gascogne) et IV (côte ibérique). On peut s'attendre à ce que la pisciculture continue à augmenter dans la zone OSPAR.

Gamme étendue d'impacts potentiels de la pisciculture et de la conchyliculture sur l'environnement

La mariculture cause un certain nombre de préoccupations: l'implantation de fermes piscicoles dans des zones marine sensibles, la prolifération d'espèces invasives et la dépendance de l'alimentation pour poisson dans la pisciculture sur les captures industrielles de poisson sauvage. Les effets locaux comportent notamment l'eutrophisation due aux aliments et aux effluents, les rejets de produits chimiques antisalissure et d'antibiotiques, le déplacement de populations d'oiseaux et de phoques causé par des dispositifs répulsifs acoustiques visant à décourager les prédateurs de poisson d'élevage et les impacts de la cueillette des mollusques et crustacés et du recueil de naissains pour la mytiliculture.

Le poisson qui s'échappe de fermes piscicoles risque d'être en concurrence avec les stocks sauvages dans les zones de frai des habitats dulcicoles. De plus, le transfert de parasites et de maladies ainsi que le brassage génétique entre le poisson d'élevage en fuite et les stocks sauvages causent des préoccupations.

Les impacts environnementaux des activités de mariculture sont particulièrement propres à un site

OSPAR a reconnu dans le passé que l'industrie de la mariculture est très diverse, ses impacts sont essentiellement propres à un site, la réglementation et le contrôle devront donc toujours de focaliser sur une approche au cas par cas et un nombre important d'orientations générales sont disponibles fournissant un contexte pour ces décisions au cas par cas. Sur cette base OSPAR avait conclu à l'époque qu'il n'était pas nécessaire de développer des programmes et mesures supplémentaires au niveau d'OSPAR.

La présente évaluation confirme, pour l'heure, cette conclusion. Il existe cependant un certain nombre d'impacts éloignés déterminés, à savoir l'introduction d'espèces sauvages, l'impact du pou de mer, les impacts écologiques et génétiques du poisson en fuite et le besoin croissant en produits de pêche industriels, qui seront passés en revue régulièrement dans le cadre d'OSPAR et celui des mers régionales. Il faut poursuivre l'échange d'informations au sujet de ces questions. De plus, les activités de mariculture devraient-elles se déplacer offshore et développer, avec d'autres activités; des méthodes d'évaluation de l'impact cumulatif de ces développements seront nécessaires.

OSPAR recommande la meilleure pratique environnementale

OSPAR recommande la meilleure pratique environnementale pour réduire les apports de produits chimiques potentiellement toxiques provenant de l'aquaculture. De plus des mesures dans le cadre des Stratégies eutrophisation, substances dangereuses et diversité biologique et écosystèmes, contrôlent, évaluent et réglementent les impacts de la mariculture. Diverses mesures de la Commission européenne traitent de la pollution et des impacts de la mariculture sur la biodiversité. Il s'agit notamment de l'utilisation en aquaculture d'espèces exotiques et d'espèces localement absentes.

Bien que les législations nationales ne mettent pas totalement en oeuvre les exigences d'OSPAR, l'intention de la Recommandation sur les produits chimiques provenant de l'aquaculture semble être réalisée par les législations nationales ou celle de l'UE. L'usage croissant de vaccins a réduit de manière significative l'utilisation d'antibiotiques en mariculture depuis les années 1980 et cette tendance se maintient depuis dix ans. Des substances à base de cuivre ont été substituées au tributylétain dans les produits antisalissure utilisés pour le matériel de mariculture; les rejets croissants de cuivre, essentiellement dans les Régions I et II causent cependant des préoccupations. La Norvège a notifié des rejets croissants d'azote et de phosphore provenant de la mariculture dans la Région I, bien qu'en Ecosse une évaluation de l'effet des nutriments provenant de la mariculture dans les lochs écossais ait conclu que ceci ne présentait pas de problème.

Meilleures connaissances, des effets de la mariculture, nécessaires

Une expansion de la mariculture pourrait diminuer la pression d'ensemble exercée sur certains stocks halieutiques sauvages. Inversement, une expansion insistant sur les poissons carnivores risque d'accroître les besoins en aliments dérivés de la pêche industrielle. L'ampleur de l'impact, aussi bien positif que négatif, de la mariculture sur les stocks halieutiques sauvages dans la zone OSPAR n'est pas claire et il est nécessaire de posséder de meilleures connaissances des interactions entre l'élevage de diverses espèces et les stocks halieutiques sauvages.

Il a été suggéré que le pou du saumon d'élevage est la cause du déclin du saumon et de la truite de mer sauvages près des fermes d'élevage de saumon. Les effets des produits chimiques et des pharmaceutiques sur le benthos et la biodiversité, notamment la réduction de leur utilisation grâce à une meilleure gestion et l'usage de vaccins contre les maladies et pour le contrôle des parasites, justifient des recherches supplémentaires.

La contribution du saumon d'élevage aux captures nationales dans l'Atlantique du Nord-est en 2007 est faible dans l'ensemble (<2% dans la plupart des pays) et similaire aux valeurs notifiées antérieurement par le CIEM. Les évaluations de l'état des stocks nationaux ignorent habituellement la présence de ces poissons. En Norvège, cependant, le saumon d'élevage continue à constituer une proportion importante des captures de la pêche côtière (29% en 2007), dans les fjords (30% en 2007) et à la ligne (9% en 2007), et la proportion moyenne de saumon d'élevage dans les stocks de frai s'élevait à 14% en 2007.

Les principaux risques causés par la fuite de poisson sont probablement dus au déplacement du poisson sauvage, aux pertes de la production et à l'intrusion génétique directe. Il est nécessaire de réaliser des recherches supplémentaires sur l'impact génétique des fuites de la mariculture sur la biodiversité, notamment la capacité des populations sauvages à se remettre de l'introgression des gènes d'élevage.

Croissance potentielle de la mariculture offshore

La mariculture offshore, seule ou conjuguée avec d'autres technologies offshore, telles que les parcs d'éoliennes, peut potentiellement s'accroître. De meilleures technologies appliquées aux cages permettent de réduire le grand nombre de fuites de poisson d'élevage.

Nécessité d'adapter les approches de gestion de la mariculture au changement climatique

L'impact de la croissance prévue de la mariculture exige une surveillance et une évaluation continues, notamment des effets sur l'état des écosystèmes. L'échange d'informations sur les impacts au niveau régional et, en tant que de besoin, le développement de cadres de travail de gestion coordonnée devront se poursuivre. L'augmentation de la température de la mer pourrait potentiellement modifier la zone où s'établissent des espèces introduites. L'huître du Pacifique, par exemple, a créé des populations sauvages en France et au Nord jusqu'au Danemark et en Suède, zones qui étaient antérieurement considérées trop froides pour permettre une reproduction viable. Le déplacement d'espèces indigènes de proie a entraîné une mortalité croissante et réduit le succès de la reproduction de certains oiseaux côtiers.

1. Introduction

In 2003 the Ministerial Meeting of the Commission adopted a Strategy for the Joint Assessment and Monitoring Programme (JAMP). This provides the framework to prepare and produce a series of thematic assessments, leading to the next comprehensive assessment: the Quality Status Report 2010. Mariculture is one of the 15 human activities that require assessment under JAMP.

Mariculture is the cultivation of marine organisms, animals and plants, in their natural habitats (*i.e.* seawater) for commercial purposes. For the purpose of this OSPAR wide assessment, “mariculture” is understood as that part of the aquaculture industry which raises and harvests fish and shellfish under controlled conditions in open systems in the OSPAR maritime area. This does not cover:

- sea ranching of fish (from wild indigenous stocks) for release into the maritime area for the purpose of fish stock management/recovery or nature conservation purposes.
- cultivation of seaweed for human consumption or use in the fertilizer, cosmetic or other industries that occurs only on a small scale in the OSPAR maritime area,
- land based aquaculture where seawater is used but is pumped to and discharged from a facility above the high water mark.

The QSR 2000 (OSPAR, 2000a) voiced many concerns over the impacts of mariculture on the marine environment. These included concerns over:

- the extent to which diseases and parasites, such as sea lice, are transferred from cultured to wild stocks, and vice versa;
- the impact of interbreeding between wild salmonid populations and escaped farmed fish;
- mariculture as a source of unintentional introduction of non-indigenous species (competitors, predators, parasites, pests and diseases); and
- the release of nutrients, organic matter and chemicals (such as colouring agents, antifouling agents, biocides, antibiotics and other therapeutants) which may cause local pollution, particularly of sediments.

Aquaculture (both marine and freshwater) is probably the fastest growing food-producing sector in the world. It now accounts for approximately 50% of the world’s food-fish and it is estimated that given projected population growth over the next two decades, an additional 40 million tonnes of aquatic food will be required by 2030 to maintain current per capita consumption (FAO, 2007). Aquaculture is perceived as having the greatest potential to meet this demand. In addition to the food requirements of growing human populations, the clearer appreciation of the health benefits of fish as part of our diet will add to the worldwide demand of aquatic food. Given the strong likelihood that fish landings will remain stagnant in capture fisheries, aquaculture remains the only apparent means to expand world supplies (WHO, 2008).

World demand for fish such as Atlantic salmon, which are near the top of the food chain, is on a steady increase. One of the reasons for this increase is the reported health benefits attributed to fish with high omega-3 oils. Predatory fish like salmon can have over four times the omega-3 content of omnivorous fish such as carp (Schipp, 2008; Anon, 2005).

In 2006, 48% of world aquaculture production was by mariculture. Of the 33 million tonnes of global mariculture production in 2006, 86% was produced by China. Almost 1.5 million tonnes or 4.5% of the global mariculture production was produced in the OSPAR maritime area.

2. What are the potential problems? Are they the same in all OSPAR regions?

2.1 Shellfish culture

Over 580 000 tonnes of shellfish was produced in the OSPAR area in 2006. The principle species cultivated are the mussels, oysters, scallops and clams. There are a variety of methods used for shellfish mariculture. Larvae or spat (seed) are collected from areas of natural settlement using structures put in place for this purpose or collected from the intertidal sea shore. Alternatively seed is produced by artificial fertilization in hatcheries. Hatchery spat are usually produced from local parent stock which can help retain the local genetic diversity of offspring. Shellfish seed are on-grown in a number of ways depending on the species and include:-

- Suspended culture - hanging from floating longlines (Figures 1 - 2), rafts, in trays, stacks or mesh bags.
- vertical or rack culture - posts, sticks or 'bouchots' (Figure 3) are staked on the bottom or trestles are used to support the shellfish off the seabed (Figure 4).
- bottom culture (Figure 5) sometimes involving shells, rocks, stones and cement slabs placed on the seabed to provide a growing site or shellfish are contained under netting (Figure 6).

 **Figure 1.** Longline mussel culture off the west coast of Ireland (© Aquafact International Services Ltd)	 **Figure 2.** Longline mussel culture viewed from beneath (© Aquafact International Services Ltd)	 **Figure 3.** Bouchot culture in France (© Ifremer)
 **Figure 4.** Oyster trestle culture (© Ifremer)	 **Figure 5**. Bottom culture of blue mussels in Ireland (© BIM)	 **Figure 6**. Clam Parc, south west Ireland

France has been using bouchots (stakes wrapped in netting containing seed, Figure 4) to culture mussels since the 13th century. Oysters are cultured both on the bottom and in bags on trestles (Figure 5). Mussel spat is collected from natural beds by dredging or scraped from intertidal rocks and is re-laid in more productive areas. The most common method for cultivating clams is the 'parc'. This is where hatchery-grown clams are placed on to the shore in netting parcs to protect the clams against predators and also to retain them within a confined area, Figure 6. Scallops can be suspended on longlines in pearl and lantern (mesh) bags or hung individually from strings (FAO, c2004 - 2008).

2.2 Finfish culture

In 2006, over 890 000 tonnes of finfish was produced in the OSPAR maritime area. The production of Atlantic salmon in Norway amounted to almost 80% of the total finfish production. The supply of eggs for finfish cultivation comes from broodstock from two sources, namely domesticated and a mixture of domesticated and wild stock. Domesticated broodstocks are cultivated to improve qualities such as growth rates, disease resistance and taste.

Larvae or 'fry' are produced in hatcheries by controlled reproduction. Following hatching, fry are conditioned to take artificial feed in tanks before they are transferred to grow-out facilities at sea (such as cages and pens, Figure 7) either by boat or helicopter. Cages can be either inshore or offshore and either floating, fixed or submerged. The choice of farm location is governed by factors including water currents, exposure to weather, other marine users, ecological and visual impacts. Finfish that are farmed in this manner include salmon, cod, sea bream, sea bass and meagre.

Figure 7. Salmon cages off the west coast of Ireland. (© Aquafact International Services Ltd)

In Spain and Portugal sea bass and sea bream are farmed in cages, similar to those used in salmon farming, and to a lesser extent in the OSPAR region IV using 'salinas' or salt pans. Salinas are natural lagoons modified for sea salt production and subsequently for mariculture, Figure 8. This process involves either using natural stock in a lagoon (by capturing fish in the lagoon during their autumn migration to the open sea), stocking it with juveniles (by allowing the lagoon to be stocked naturally with fry and then closing off the portion of the lagoon which is open to the sea using nets, reeds or concrete) or by stocking with hatchery produced fry. The quantity of fish produced in salinas is relatively small.

Figure 8. Salinas lagoon system south of Cadiz, Spain. Source: Google Earth.

2.3 Trends in mariculture production in the OSPAR area

Table 1 lists the species currently cultivated in each country in the OSPAR maritime area. A full description of the biological features, habitat and biology, production methodology, statistics and costs, diseases and controls for mariculture species within the OSPAR area can be reviewed at http://www.fao.org/fishery/culturedspecies/search.

Tables 2 and 3 show the production of shellfish and finfish in each OSPAR Region for the period 1998 to 2006. These data were compiled from the FAO FishStat website and information supplied by Contracting Parties. Greater detail of production figures and species is available from the FAO website, (FAO, 2008). Total mariculture, finfish and shellfish, produced in the OSPAR maritime area was over 1.4 Mt in 2006, of which 60% was finfish production. Every effort was made to use production values for the OSPAR maritime area only. Where possible, mariculture production in the Mediterranean and Baltic Seas were removed from the FAO data. While this was possible in the majority of cases it was not in all. Any inaccuracies, however, are considered unlikely to significantly change the outcome of this assessment.

Table 1. Mariculture species cultivated in the OSPAR area.

Species	Country
mussels	
Mytilus edulis	Norway, Sweden, Netherlands, Ireland, United Kingdom, Germany, France, Spain, Belgium
Mytilus galloprovincialis	France
oysters	
Ostrea edulis	Norway, Netherlands, Ireland, United Kingdom, France, Spain
Crassostrea gigas	Norway, Ireland, United Kingdom, Germany, Channel Is., France, Spain, Portugal
clams	
Mercenaria mercenaria	France
Venerupsis pullastra	Spain, Portugal.
Ruditapes decussatus	France, Spain, Portugal
Ruditapes semidecussata (= Tapes philippinarum)	Ireland, United Kingdom, France, Spain, Portugal
scallops	
Pecten maximus	Norway, United Kingdom (Scotland), Ireland, Spain, France
Aequipecten operculis	Norway, United Kingdom (Scotland)
Aequipecten varia	France
salmon *Salmo salar*	Iceland, Norway, Finland, Faeroe Is., Ireland, United Kingdom, France, Spain (Spain no marine salmon since 2005 – restocking landbased only)
sea trout *Salmo trutta*	United Kingdom (Scotland)
rainbow trout *Oncorhynchus mykiss*	Iceland, Norway, Sweden, Denmark, Netherlands, Faeroe Is., Ireland, United Kingdom, France, Spain, Portugal, Belgium
coho salmon *Oncorhynchus kisutch*	France
European seabass *Dicentrarchus labrax*	Iceland, France, Spain, Portugal
meagre *Argyrosomus regius*	France
gilthead seabream *Sparus aurata*	France, Spain, Portugal
cod *Gadus morhua*	Norway, Iceland, United Kingdom (Scotland), France
halibut *Hippoglossus hippoglossus*	Iceland, Norway, United Kingdom (Scotland)
turbot *Psetta maxima*	Spain, France and Portugal, Germany, Iceland, Ireland, Norway, United Kingdom
hake *Merluccius merluccius*	Norway
haddock *Melanogrammus aeglefinus*	Scotland (evaluation 2002), Norway (broodstock), Iceland
wolf fish *Anarhichas minor*	Norway
Dover sole *Solea solea*	Spain
saithe *Pollachius virens*	France, Spain

Table 2. Shellfish production (tonnes) 1998 – 2006 in the OSPAR Regions by Contracting Party. Data compiled from FAO database (FAO, 2008) and submissions from Contracting Parties.

Country	Region	1998	1999	2000	2001	2002	2003	2004	2005	2006
Norway	I		393	655	359	823	528	1869	1979	2007
Iceland	I						4	4	4	
Channel Islands	II	196	248	388	485	579	684	775	650	660
Denmark	II						11	55	280	411
Sweden	II	455	925	443	1444	1382	1742	1435	1069	1791
Norway	II		376	242	586	1759	1307	1949	2924	1742
Germany	II	31288	38039	24207	11723	8103	28634	12559	9555	3756
France	II	89525	91058	94559	80120	83092	78759	90343	90088	82050
Netherlands	II	115887	103989	68892	51557	47912	58965	70073	62695	34495
Scotland	II	200	202	408	832	1340	1583	2206	2161	2343
England	II				5224	2069	2822	3778	3661	3884
Ireland	III	25239	23516	31110	35853	37594	44678	43092	44666	40396
Scotland	III	1611	1570	1943	2518	2218	2408	2367	2303	2319
England	III				40	40	40	40	40	40
Wales	III	10256	9039	10043	8584	10974	15238	4344	16364	10170
N. Ireland	III	512	569		1321	1102	5134	4604	7495	10346
Portugal	IV	3749	1804	2919	3164	3737	3584	2681	2194	2790
France	IV	89525	91058	94559	80120	83092	78759	90343	90088	82050
Spain	IV	269708	272227	256359	252823	265171	252369	299268	211405	305109
Total		**638151**	**635012**	**586726**	**536753**	**550986**	**577249**	**631784**	**549620**	**586359**

FAO data for France subdivided into OSPAR Regions on the basis of information from CNC 2009.

Table 3. Finfish production (tonnes) 1998 – 2006 in the OSPAR Regions by Contracting Party. Data compiled from FAO database (FAO, 2008) and submissions from Contracting Parties.

Country	Region	1998	1999	2000	2001	2002	2003	2004	2005	2006
Norway	I	250364	303112	303490	314145	369489.3	360257.6	415073	418310	482879
Iceland	I	2214	2410	2094	2672	1582	2495	4823	4868	6352
Faeroe Is	I	20436	42544	34823	49167	56102	62746	46077	23455	18574
Denmark*	II	600	600	600	600	600	600	600	600	600
Sweden	II	2	5	0	0	9	0	0	0	0
Norway	II	160092	173210	188810	196727	181884	220389	219778	233992	225679
France	II	650	1379	560	504	957	724	925	1284	1410
Scotland	II	38568	41292	49538	45338	55990	72531	61837	44382	46687
Ireland	III	15906	19153	19008	24289	24119	16717	14349	14481	11720
Scotland	III	72720	86523	80266	93849	89875	99014	97687	86864	88488
Wales	III	0	0	0	0	0	12	12	0	0
Portugal	IV	1732	2068	2487	2711	2675	2840	2925	3110	2859
Spain	IV	5844	6979	7919	7673	8466	8383	9044	9300	10477
Total		**569128**	**679275**	**689595**	**737675**	**791748**	**846709**	**873130**	**840646**	**895725**

*Denmark reported approximately 600 tonnes rainbow trout annually in Region II.

Figures 9 and 10 chart mariculture production trends per OSPAR region for shellfish and finfish mariculture over the period 1998 to 2006 and is prepared from the information provided in Tables 2 and 3.

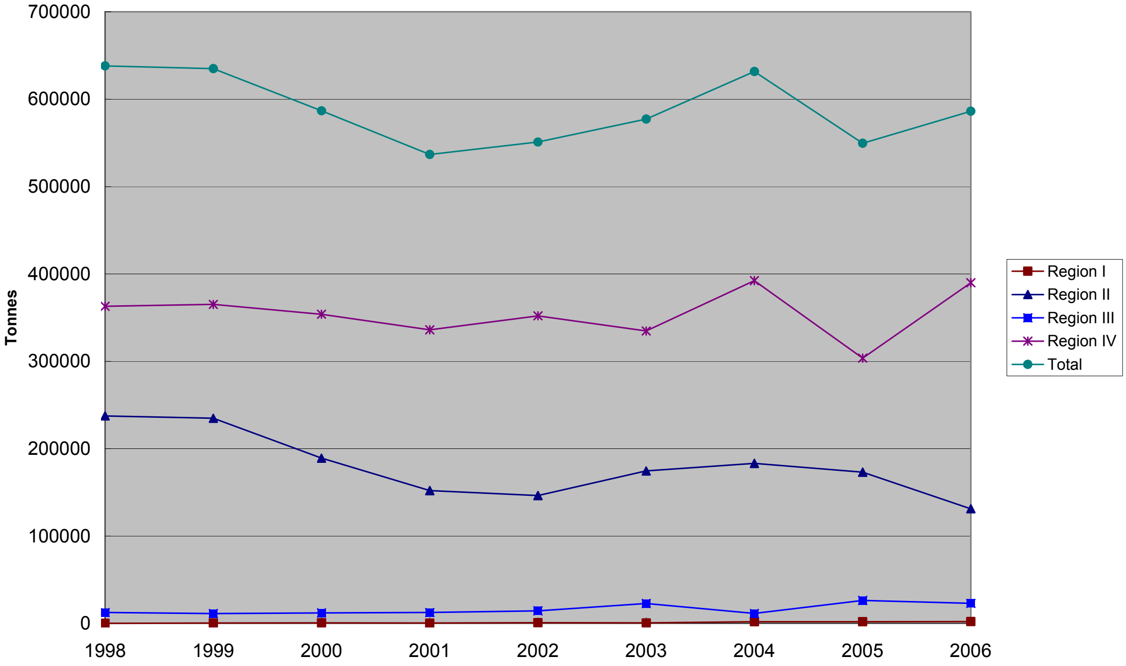

Figure 9. Total mariculture shellfish production (1998 – 2006) for the OSPAR Regions based on data from the FAO FishStat 2008 website and submissions from Contracting Parties. No shellfish were cultivated in OSPAR Region V. Values are for marine aquaculture in OSPAR regions only.

Shellfish production for the OSPAR maritime area was relatively stable, ranging between 536 753 and 638 151 tonnes over the period 1998 to 2006. Figure 8 shows the total shellfish production for the OSPAR area as well as production for the different OSPAR Regions over that period. Shellfish production increased from north to south with no production recorded for Region V. The fluctuation in production between 2004 and 2006 was due mainly driven by the fluctuation in Spanish shellfish production in Region IV. The decrease in Region II was primarily due to decreases in production in the Netherlands and, to a lesser extent, Germany and France. Shellfish production in Region III was relatively constant over the period and negligible in Region I with no shellfish cultured in Region V.

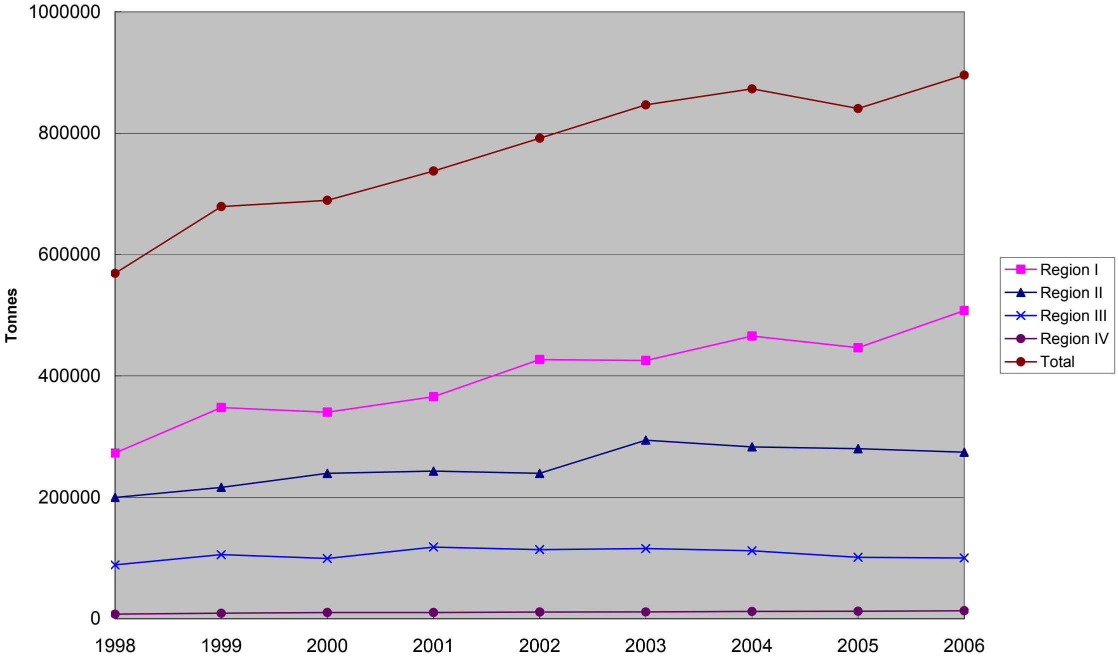

Figure 10. Total mariculture finfish production (1998 – 2006) for the OSPAR Regions based on data from the FAO FishStat 2008 website and submissions from Contracting Parties. No finfish were cultivated in OSPAR Region V. Values are for marine aquaculture in OSPAR regions only.

The available information on the locations of the mariculture sites in Contracting Parties is shown in Appendix I. Mariculture production of shellfish and finfish per km of coastline in different parts of the maritime area is shown in Figures 11 and 12.

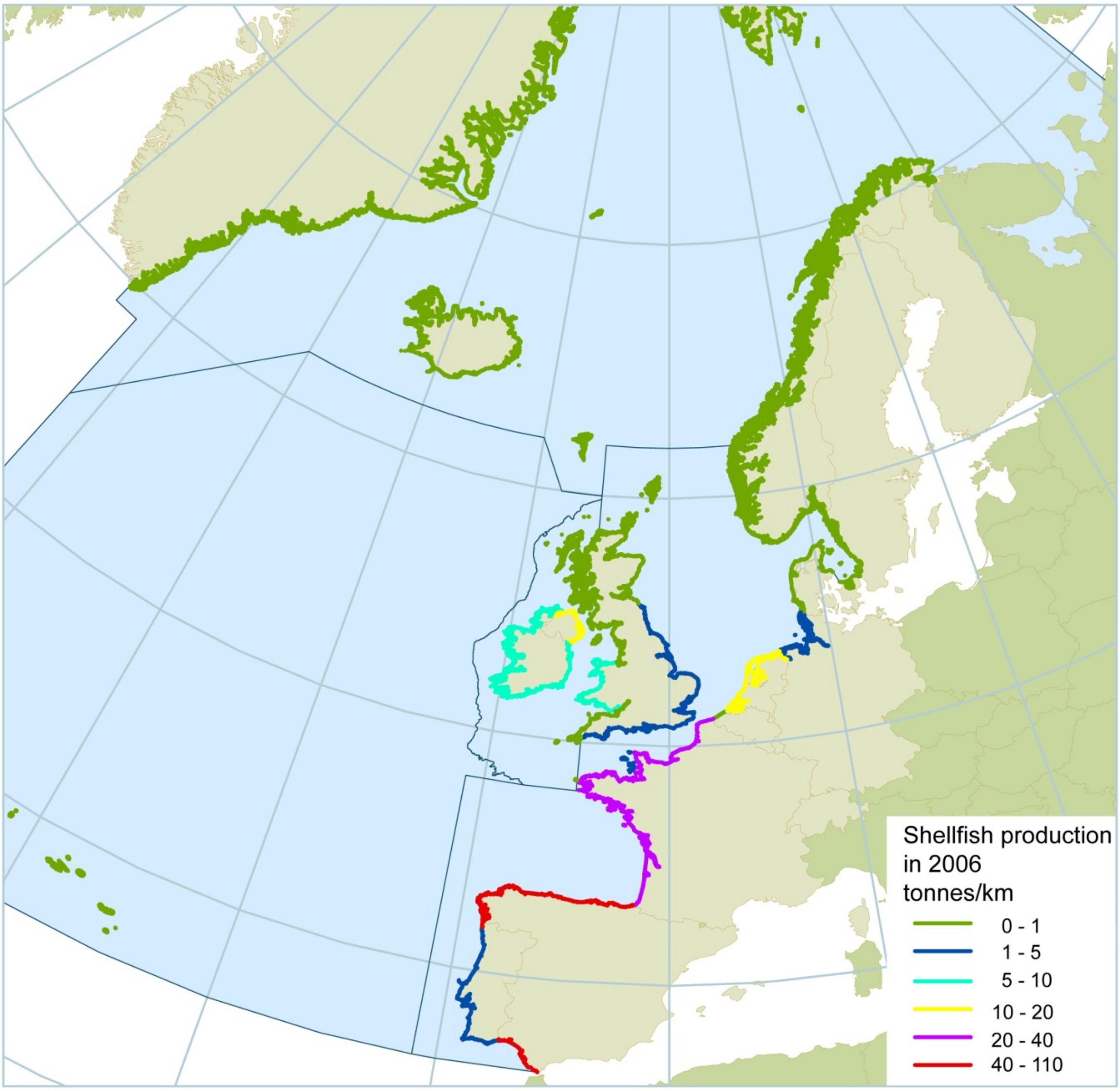

Figure 11. Production of shellfish per km of coastline for 2006. Data presented on a state by state, region by region basis, *e.g.* England in region II and III. Data from the FAO FishStat 2008 website and submissions from Contracting Parties. No shellfish or finfish were cultivated in OSPAR Region V.

Figure 11 shows an increase in production per km of coastline from north to south for shellfish and Figure 12 shows the reverse, an increase in production from south to north for finfish. For shellfish, the Spanish, followed by the French coastline are the most intensively farmed, whereas for finfish, the coastline of the Faeroe Islands, followed by Norway and Scotland are the most intensively farmed.

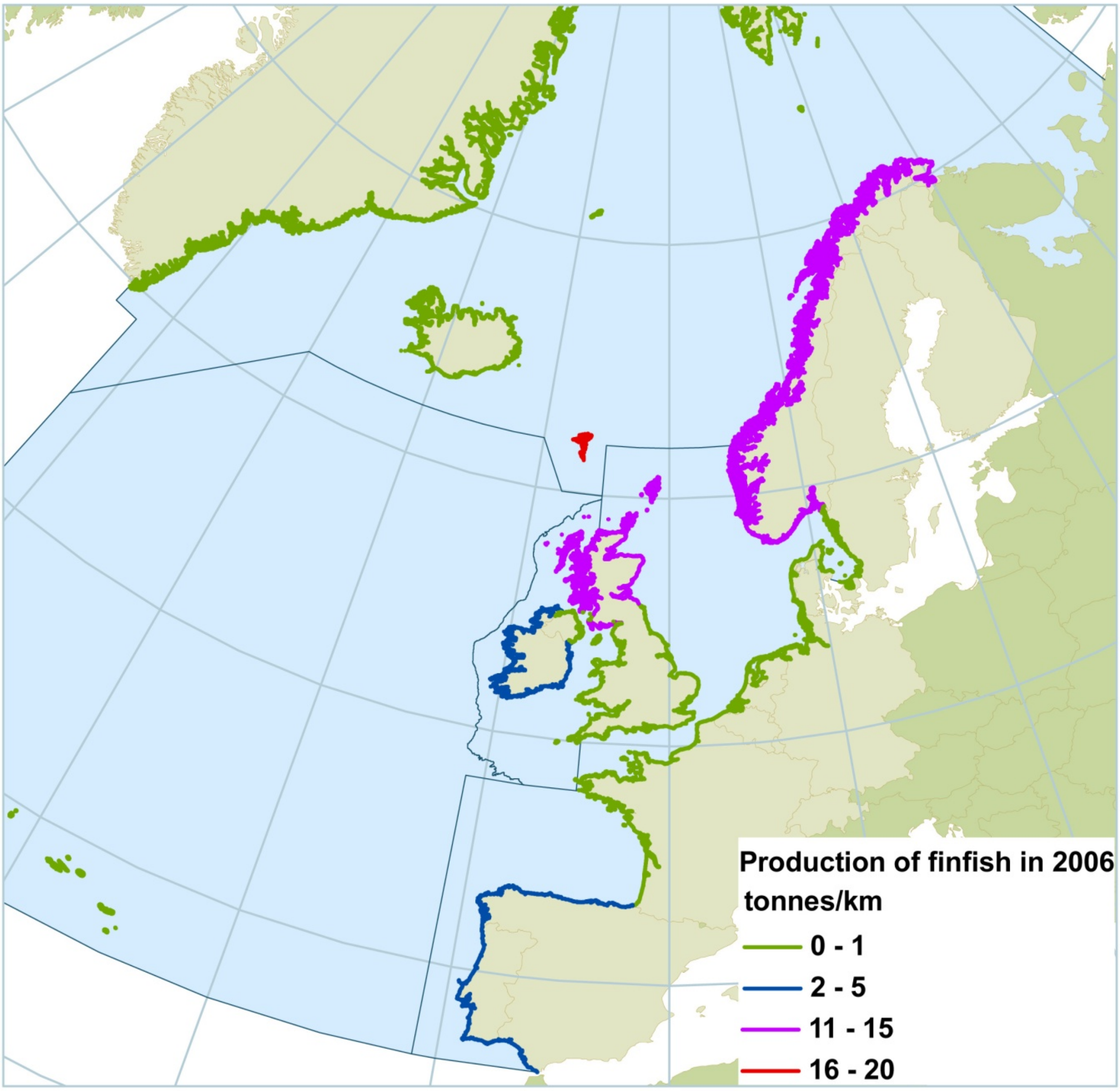

Figure 12. Finfish production per km of coastline for 2006. Data presented on a state by state, region by region basis, *e.g.* England in region II and III. Data from FAO FishStat 2008 website and submissions from Contracting Parties. No shellfish or finfish were cultivated in OSPAR Region V.[1]

When viewed at a regional and sub regional level and using farming intensity as a proxy for environmental pressure, the Faeroe Islands, Norwegian and Scottish coasts (Regions I, II and III) are most exposed to pressures from finfish mariculture and the Spanish and French coasts (Regions II, III and IV) to shellfish mariculture.

Aquaculture provided 45% of the world's fish and fish products in 2005 as against 9% in 1980. Europe produced 1.54 million tonnes of cultured fish and shellfish in 2005. The fourth assessment of Europe's

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[1] Additional information from Norway: The intensity of finfish production in terms of tonnes per km of coastline (including islands) varies along the Norwegian coast between 1.4 (South), 13.6 (Mid-Norway) and 6.5 (North). Average production in Region I is 8.5 tonnes/km and 8.4 tonnes/km in Region II. Please note that these calculations are based on coastline length provided by the Norwegian Mapping Authority, which are differing somewhat from the figures used for preparation of the map (World Vector Shoreline)

environment (EEA, 2007) identified aquaculture as a pressure on the marine environment. The report identifies the main impacts as:

- eutrophication and localised enrichment of sediments;
- the potential to contribute to over fishing of certain wild fish stocks to provide fishmeal and oil to feed farmed fish;
- release of disinfectants, pesticides, biocides and anti-fouling agents to the marine environment;
- potential transfer of parasites and diseases to wild populations;
- accidental introduction of non-native species, *e.g.* with the deliberate introduction of non-native shellfish for culture purposes:
- genetic impoverishment of wild stocks by breeding with escapees from farms; and
- competition for space, interaction and conflict with predators.

2.4 Generic impacts of mariculture

Mariculture can affect different parts of the marine environment. The generic environmental impacts of mariculture activities are illustrated in Figure 13 and listed in Table 4 along with possible mitigating measures to control impacts.

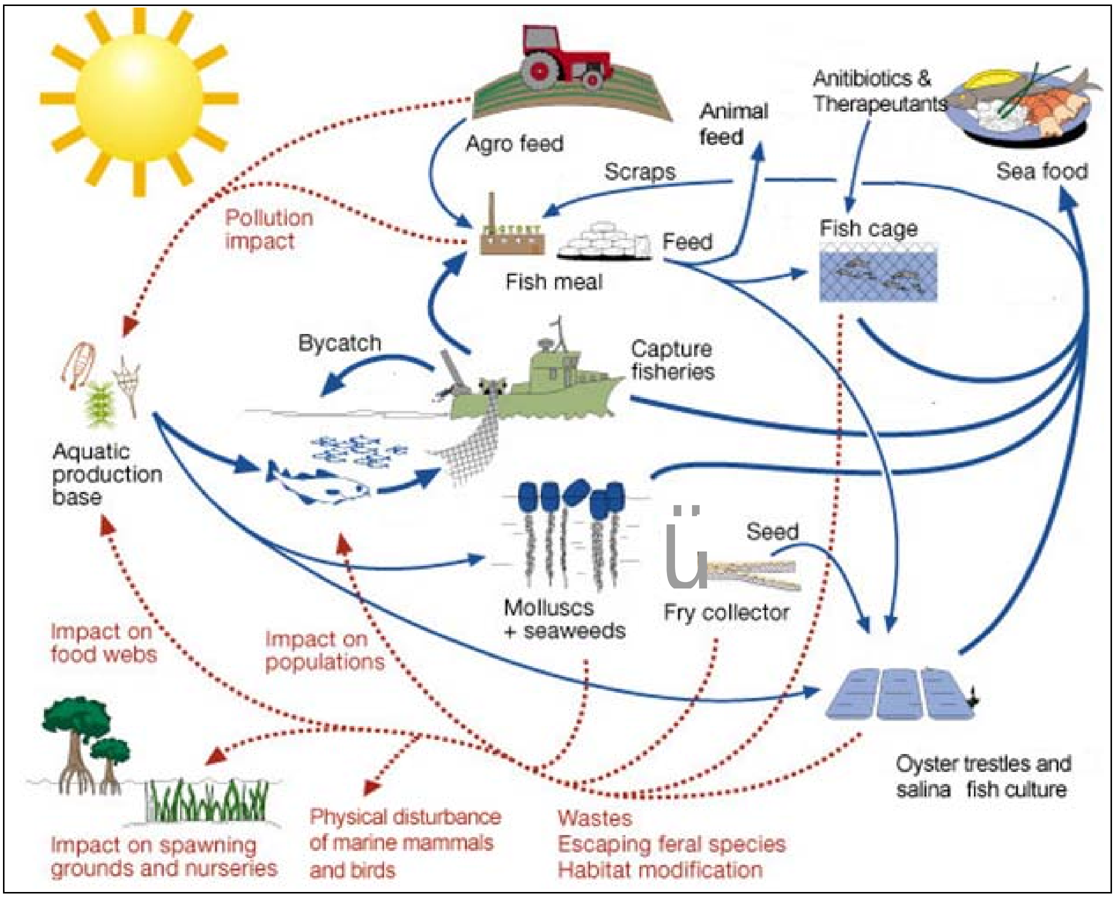

Figure 13. Different receptors of the marine environment affected by mariculture.
(Adapted from Naylor *et al*., 2000)

Table 4. Environmental impacts of fish farms: sources, types, receptors, effects and possible controls.

Source	Type	Impact On	Effect	Control
Uneaten food, faeces, pseudofaeces, scales.	Solid organic	Seafloor ±100m	Enrichment, elimination of fauna. H_2S outgassing	Improve feeding, site rotation and harrowing
Excreta and food leachate	Soluble organic	Water – generally localised	Eutrophication and toxic ammonia	Site selection and rotation
Harvesting and seed dredging	Ecological change Physical	Fish, benthic communities, seabed habitat damage.	Wild and commercial stock viability and habitat destruction	Fisheries and seed management
Therapeutants, antifoulants, feed additives, disinfectants, net washings	Chemical contamination	Water, sediments and biota	Toxicity to organisms, water and sediment quality, food chain	Proper usage, good husbandry, site selection and mechanical cleaning
Escapees	Ecological change	Wildfish, ecosystem, and habitat.	Disease, sea lice, genetic, competition and displacement	Site and equipment selection, maintenance, marking, recapture, containment
Stock	Disease parasites reservoir	Wildfish and wild shellfish	Infections and disturbance	Site selection, management, husbandry, treatment
Translocation of stock	Alien species	Ecosystems and habitats	Displacement, competition	Certification of stock, containment and restriction of movement
Predation	Behavioural	Birds and mammals	Mortalities, behavioural	Predator nets, scarers
Access and onsite activity	Visual disturbance, compaction	Birds, mammals, seabed,	Disturbed feeding and roosting	Limited access (frequency and timing), single access route
Space utilisation	Physical Presence	Other Users	Visual impact, navigation, other users	Site selection, spatial planning, marking

2.4.1 Alien species

A significant portion of mariculture in the OSPAR area is reliant on non-native species (for example, Pacific oyster *Crassostrea gigas*). Concern is increasing about the impacts of introduced species on marine ecosystems. If allowed to escape, these species may establish breeding populations and dislodge native species from established niches. Non-reproducing alien species may also interact with native species and affect predation and competition for food. Mixing of exotic genes through hybridisation, habitat modification and the introduction of diseases and parasites are other areas of concern. There has been little research to date on the ability of natural populations to recover from introgression of farmed genes (CBD, 2004).

It is likely that new alien species will continue to be introduced to supply the needs of the growing aquatic food market. It is therefore important to have procedures in place to assess the risks and benefits associated with the introduction of alien species into an ecosystem and, if appropriate, to develop and implement a plan for their introduction and responsible use (FAO, 2005). Several programmes have recently been introduced to manage the threat of invasive species, including the European Strategy on Invasive Alien Species as established under the Berne Convention (2003) in accordance with the Guiding Principles for Invasive Alien Species under the Convention on Biological Diversity (see Section 3.1 for further detail).

Several non-native marine organisms have become established after being accidentally introduced with imports of bivalve mussel seed (Kaiser *et al*., 1998). These include the American slipper limpet (*Crepidula fornicata*) which competes with native bivalves, and diseases such as Bonamia which infect oysters and was introduced from the USA.

The introduction of some non-native bivalve species for cultivation in some OSPAR regions was carried out in the belief that the temperature would be too low for larval production and recruitment to occur. Species such as the Pacific oyster (*Crassostrea gigas*) (see case study below) and the Manila clam (*Ruditapes philippinarum*) are important mariculture species which have become established in the wild. It was initially assumed that natural spatfall of *C.gigas* would not occur in higher latitudes (such as the United Kingdom, Ireland, Netherlands and Germany) as the water would be too cold for reproduction. However this was not the case and successful populations are now widespread as far north as the Wadden Sea (Wehrmann *et al*. 2000) and Limfjord in the north of Denmark (Christensen and Elmedal, 2007). It has been estimated that up to 32 alien species have been imported into the OSPAR region as a result of the movement of this species (Reise *et al*., 2002).

The Manila clam was introduced for culture in southern England in the late 1980s. This species has naturalised in Poole Harbour in Dorset (Jensen *et al*., 2004) and, in a previously unknown predator-prey interaction, is being exploited by the Eurasian oystercatcher (*Haematopus ostralegus*). It has continued to spread around European coastal waters, a process likely to be facilitated by increased temperatures due to climate change. The establishment of clam populations could have benefits for many shellfish-eating shorebird populations (Caldow *et al*., 2007) but the extent of the impact of this species depends on the density of established populations.

Increasing sea temperatures due to climate change may mean that it will become possible to farm warmer water species further north. In addition to the northerly range extension of Pacific oysters and Manila clams, the ranges of turbot, sea bass and scallops may also extend northwards. While this may be of benefit to mariculture in Northern countries, the northward shift of southerly species ranges may have a negative effect on southern and central European countries such as Spain and France where mass mortalities of Pacific Oyster have occurred in recent years. Summer mass mortalities can be caused by the cumulative effects of spawning (the energy expenditure of which reduces thermal tolerance) and heat shock – conditions which may become more frequent due to climate change (Li *et al*., 2007).

2.4.2 Waste disposal

Shellfish and finfish mariculture produce different types of waste with different problems and solutions to dealing with it. In general shellfish waste is generated on land and legislation covering the disposal of waste is controlled by normal waste legalisation.

There is also the potential for reuse of aquaculture wastes for example the use of bivalve mollusc shells as ‘cultch’ to encourage settlement of mussel and oyster spat. The integration of fed mariculture (finfish fed by food pellets) with extractive mariculture (shellfish and seaweed) is a potential method of reducing waste. The wastes of one activity may be a resource (fertiliser or food) for the others. At least 80% of the total nitrogen lost from fish farms is available for uptake by marine plants (algae and phytoplankton) and fish excreta and waste fish food provide well balanced nutrients for algal growth (Scottish Executive Research Unit, 2002).

In the United Kingdom, the Fisheries Research Services (FRS) in Scotland in collaboration with the Centre for Environment, Fisheries and Aquaculture Studies (CEFAS) and Scottish Quality Salmon (SQS) are evaluating alternative technologies for the safe and effective treatment of aquaculture wastes. A number of emerging technologies have been identified which provide new possibilities for treatment and disposal of fish wastes, for example, composting, modified ensiling processes, alkaline hydrolysis and fish protein hydrolysate. Additionally work is underway to establish the extent to which fish pathogens are inactivated under a range of conditions, including heating and acids and alkali treatments.

Council Regulation (EC) No. 1774/2002 establishes the health requirements concerning animal by-products not intended for human consumption. This requires member states to ensure adequate arrangements are in place to enable animal by-products to be disposed of in accordance with the regulation. Fish farmers are required to dispose of their fish waste in line with the regulations which include a ban on the use of landfill as a disposal method for raw fish farm waste.

Pacific oyster - Case Study.

The Pacific oyster, *Crassostrea gigas*, has been cultured successfully worldwide throughout 20th century (Diederich *et al.* 2005). It was introduced throughout Europe to replace the declining populations of the native oyster, *Ostrea edulis* and the Portuguese oyster, *Crassostrea angulata* (Ruesink *et al.,* 2005).

On its introduction to Europe it was assumed that natural spatfall of *C.gigas* would not occur in higher latitudes (such as the United Kingdom, the Netherlands and Germany) due low water temperatures. However, this species has demonstrated a wide thermal tolerance and they can grow in water between 4º – 35 ºC (Nehring, 2006). They can also tolerate very low salinities (approximately 5%) for short periods. Fecundity is high with females producing 20 – 100 million eggs per spawning. The free-swimming planktonic larvae can spend up to three weeks in the water column before finding a suitable clean substrate to settle on, potentially giving them a wide dispersal range.

Wild populations of *C.gigas* became established in The German Wadden Sea in 1991 (Nehring, 2006). Since then, it has expanded its range northwards as far as the Danish Wadden Sea which was reached in 1999 (Reise *et al,* 2005). *C.gigas* is now established / naturalised in Belgium, Denmark, France, Germany, Ireland, the Netherlands and the United Kingdom (Ruesink *et al.,* 2005). There are also records of limited spread as far north as Norway and Sweden (ICES, 2008).

C.gigas forms solid reefs and their role as ecosystem engineers is particularly pronounced in soft sediment environments such as the mudflats of the Wadden Sea where hard substrate is rare except for mussel beds and oyster shells (Ruesink *et al.,* 2005; Kochmann *et al.,* 2008). In the northern German region of the Wadden Sea, *Mytilus edulis* beds are declining while wild populations of *C.gigas* appear to be increasing. It would appear changing climate over the last decade is the primary cause of this shift. As yet, there is no strong evidence that *C.gigas* has caused the decline of the native mussels (Nehls *et al.,* 2006; Nehls and Büttger, 2007). However, community structure differs between habitats created by oysters and mussels, with concomitant implications on their overall function in the marine environment (Kochmann *et al.,* 2008).

With the high reproductive capacity demonstrated by *C.gigas*, its considerable adaptability to changing conditions and the large standing stock in the OSPAR region, *C.gigas* must now be considered a permanent constituent of the European coastal ecosystems (Nehls and Büttger, 2007). Future management strategies must consider the influence this species has on the form and function of these marine systems.

Farming of *Crassostrea gigas* near the German island of Sylt, April 2003, left picture. Oyster reef *Crassostrea gigas* in the German Wadden Sea near the island of Sylt, January 2005, photos by Stefan Nehring. Source: Nehring, S. 2006. NOBANIS – Invasive Alien Species Fact Sheet

2.4.3 Impacts on birds and mammals

Sea-cages and shellfish structures in coastal waters have long been known to be a focus for many species of predatory and scavenging bird species (cormorants, shags, herons, gulls and eider ducks) attracted by feeding opportunities around mariculture sites. In addition to the food within the cages and shellfish structures, the shelter they provided also attracts wild fish.

Impacts of mariculture detrimental to birds include avoidance of feeding areas due to human activity (human presence, increased boat traffic, scaring devices) and entanglement with cage nets.

The disturbance of intertidal sediments by invasive commercial bivalve harvesting activities (for example clam *Ruditapes semidecussata*) is of concern because of the physical disturbance of the substratum and associated fauna and the direct interference with the feeding behaviour of wading birds (oystercatchers). In 1990 and 1991 over-exploitation of the mussel seed stocks in the Wadden Sea caused the depletion of the entire intertidal mussel stock. As a result, there were increased mortalities of eider duck and reduced breeding success for oystercatchers which depend on mussels as a food source (Kaiser *et al*., 1998). However, some beneficial impacts of shellfish mariculture include over wintering populations oystercatchers which have been studied exploiting naturalised populations of manila clams in Poole in southern England (Caldow *et al.,* 2007).

Marine mammals are also attracted by the high density of available food associated with fish farms. Seals in particular can benefit from the additional haul out points and food-filled cages, feeding, damaging cages and increasing escapees. While there is evidence of dolphins being attracted to aquaculture facilities, the siting of these facilities is an important initial preventative measure in predator control. Locating cages away form places where mammals and birds typically hunt and congregate will reduce the impacts aquaculture has on these animals.

Scaring devices are often used to prevent otters, seals and cetaceans from feeding on captive fish. While acoustic deterrent devices continue to be used, mammals and birds have shown ability to acclimatise to the noise these devices make. Cetaceans are particularly sensitive to predator control acoustic devices. Unlike seals however, they have not been reported to consume fish or shellfish out of farms but have been known to become entangled in equipment resulting in damage to gear, fish escapees and self-injury (Kemper and Gibbs, 2001; Crespo and Hall, 2002). Lopez *et al.* (2005) reported that studies on bass and gilthead sea bream farms in Sardinia seemed to indicate that bottle nosed dolphins were attracted by an intensification of aquaculture activity and fed on the wild fish which were gathering around the cages to feed on excess feed pellets.

It is not unknown for mammals to be shot. The scale of such killing is uncertain, as it does not necessarily need to be reported in all OSPAR countries. For example, according to official figures more than 60 harbour (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) were legally shot under licence by Scottish fishery boards during the year 2000.

Fish farmers can surround the cages with predator nets which minimise or eliminate the need for killing seals or using acoustic deterrent devices. There are reports of incorrectly fitted predator nets trapping and drowning seals.

Boat activity associated with finfish and shellfish farming has the potential to cause disturbance to seals, particularly during breeding, pupping and moulting seasons.

2.4.4 Effects of climate change on the impacts of mariculture

Climate change is expected to heavily influence mariculture in the coming years. Sea surface temperatures (SST) are increasing throughout the OSPAR area. SST and air temperature over the mid-Atlantic and around the United Kingdom and Ireland have been rising by 0.2 – 0.6 ºC per decade over the last 30 years and warming is greatest in the North Sea and English Channel where temperatures have risen faster than land temperatures. Summer precipitation is predicted to decrease (0 - 10% by 2020 and 10 – 30% by 2080) and winter temperature are predicted to increase (10 – 15% by 2080) (Gubbins, 2006).

There is uncertainty as to the nature and extent of the impacts of climate change. Increasing sea temperature may result in farmed species range shifts. This may mean that warmer water species which are currently grown in more southern European countries will become possible to farm in northern waters. These species include sea bass, sea bream, pacific oysters, manila clam and scallops. While this may be of benefit to Norwegian mariculture, the northward shift of southerly species ranges may have a devastating effect on southern and central European countries such as Spain and France. Pacific oysters (*Crassostrea gigas*) are susceptible to occasional mortality events during prolonged periods of hot weather and incidence of this may increase with increasing water temperatures.

In addition to species range shifts rising water temperatures will increase the growth rate for some species (for example Atlantic salmon, mussels and oysters), but prolonged periods of warmer summer temperatures may cause thermal stress, particularly for cold water species (for example, cod and Atlantic halibut) and intertidal shellfish (oysters), possibly preventing their culture at some sites, causing welfare problems and necessitating temperature control for broodstock of some species (Gubbins, 2006).

This change in temperature is likely to result in increased reproductive potential of salmon lice and other parasites. To combat this there may be an increase in the use of chemical therapeutants and their input into the marine environment. Diseases of cultured fish and shellfish (including bacterial, viral and fungal diseases), will also be affected by a changing thermal regime although to what extent is still uncertain. However, under conditions of thermal stress, cultured species are likely to be more susceptible to disease. Warmer conditions may also allow the establishment of exotic diseases, whereas diseases that occur under cool conditions, for example, cold water vibriosis, may become much rarer (Gubbins, 2006).

Increased storminess (higher frequency of strong wind speeds) predicted for certain seasons in some regions such as the North West coasts of Scotland and Ireland and Norway will increase the risk of escapes through equipment failure increasing the impact of escapees on wild populations. Relocation or improvement in equipment may offset these impacts.

Decreased precipitation could alter flushing times in bays and estuaries where mariculture is carried out. This could result in an increase in the accumulation of waste in the seafloor. Predicted sea level rise and erosion of intertidal zones by increased storm activity could reduce the area available to many forms of mariculture especially in vulnerable areas such as lagoons and estuaries in Portugal and Spain (Ferreira *et al.,* 2001).

2.5 Impacts of shellfish mariculture

Shellfish farming tends to have a limited impact (compared to finfish farming) primarily because there are no direct inputs of food or chemicals. The impacts of shellfish farming such as mussel, oyster, clam and scallop farming are mostly generic and include ecosystem impacts from the introduction of alien species, physical disturbance from dredging and presence on the foreshore. These are discussed further in the following sections.

2.5.1 Parasites and diseases

There is good evidence that some parasites are capable of transmitting from farmed to wild populations and in some cases this may be harmful. For example, in molluscs, the pathogen *Bonamia ostreae* was introduced to Europe with infected flat oyster spat from the USA in the 1970s. There is an extensive trade with shellfish spat and juveniles throughout Europe and the disease spread rapidly due to movements of infected oysters. All of the countries that are affected by this disease have been unable to eradicate them.

The slipper limpet (*Crepidula fornicata)* was introduced from North America towards the end of the 1800s. It is typically found attached to shells and stones on soft substrata around the low water mark where it competes with other filter-feeding invertebrates for food and space, and often occur in enormous numbers. Few management options are available to combat this species. Dredging operations to clear slipper limpets from oyster beds have been attempted in some areas, but it was concluded that further spread of the species could not be prevented (Global Invasive Species Database). It has been reported to alter sediment characteristics by removing a huge volume of suspended organic material from the water column, and depositing that filtered material on the bottom as pseudofeces. It can be found on coasts from the Mediterranean to Norway with highest densities on the west coast of France, southern coast of England and the Netherlands and impacts include changes to trophic structures and macrobenthic communities (Thieltges *et.al*. 2003).

2.5.2 Dredging

Dredging for seed and the harvesting of on-bottom culture shellfish impacts the seabed and benthic communities as well as non target commercial species such as wild scallops and clams. Natural mussel seed settlement tends to occur in localised areas – although these may change from season to season. In the United Kingdom seed mussels are dredged once a layer of mussel mud has built up (mussel mud is an accumulation layer of mussel faeces and pseudofaeces which can be 30 to 40cm thick and can detach from the underlying substratum and become unstable). This allows the collection of seed mussels with a relatively small impact on the subsurface fauna. In addition, dredging activities are seasonal, which will allow a period of recovery for the seabed habitat and the benthos. In the Netherlands, the harvest of intertidal mussel seed beds is only permitted in autumn on unstable beds which are susceptible to being flushed away during winter storms (Maguire *et al*., 2007). Of more concern is the over-exploitation of mussel seed resources, especially considering the increase in demand for such seed in recent years. For example in 2003, the seed requirement for the Irish mussel industry was estimated at 180 000 tonnes, but the supply was only approximately 30 000 tonnes (FAO, 2004; FAO, 2008). In 1990 and 1991 almost the entire intertidal Dutch Wadden Sea mussel stock was removed by mussel seed harvesting which resulted in increased mortality for Eider ducks and a reduced breeding success for oystercatchers (Kaiser *et al*., 1998). Oystercatchers also sought alternative prey including various cockles, *Macoma balthica* and juvenile *Mya arenaria* which subsequently suffered high rates of mortality (Beukema, 1993). Dredging of mussel seed beds will also release sediment and mussel mud into the water column which following sedimentation can cause enrichment. This is discussed further below.

2.5.3 Artificial production

Artificial production of seed in hatcheries can also have impacts. The use of parental stock from the local region to produce mollusc seed may help retain the genetic diversity of regional parental stock. However, because of the high fecundity of molluscs it only takes a few animals to sustain seed production potentially leading to negative impacts on the genetic diversity of the reared population. Even a small degree of inbreeding as a result of this can have an impact on fitness such as a significant depression in yield, growth rate and survival rate at both larval and adult stages (Ford *et al.,* 2004). Research is continuing to define the number of broodstock required to maintain genetic diversity and further research into the biodiversity impacts of such occurrences is required (CBD, 2004). Introduced species of bivalves may hybridise with wild species, thus weakening the genetic integrity of the native populations. Such hybridisation is occurring between the Portuguese oyster (*Crassostrea angulata*) and the Pacific oyster (*C.gigas*) between France and Portugal.

2.5.4 Nutrient enrichment and benthic environment

Sediments under intensive shellfish farms can become anoxic giving rise to outgassing of hydrogen sulphide and a decrease in species numbers and diversity in sediments (Figure 14) although this effect is generally only present at very large sites with limited tidal exchange. Bivalve pseudofaeces are rich in nitrates, ammonium and phosphates. These wastes change the composition of sediments underneath the shellfish farm. Rafts and longlines also become fouled with green algae which will increase levels of organic enrichment when algae die back in autumn and winter. Harvesting has the net effect of removing nutrients from open systems. Barnes (2006) reviewed the literature on shellfish particulate matter production. All studies report increased levels of suspended sediments under the farms resulting from the deposition of pseudofaeces which in turn impact the benthos. Sensitive taxa such as decapods, infaunal bivalves and echinoderms cannot exist in sediments with low oxygen levels and are replaced by less sensitive polychaete taxa such as *Spionidae*, *Cirratulidae* and *Dorvilleidae*. Impacts are considered to be lower under longlines than under rafts as the amount of pseudofaeces falling from longlines is spread over a larger area. Tenore and Gonzales (1975) record high primary and secondary production on the mussel lines which in turn give rise to increased numbers of fish around the farms.

2.5.5 Intensive shellfish over-grazing

Intensive shellfish farming by its nature strips primary production from the water column and if a bay is too heavily farmed, there can be ecological impacts due to over-grazing on phytoplankton. Models have been developed to determine the optimum stocking density at which shellfish production is maximised without negatively impacting growth rates and minimising the impact on the environment (Kaiser and Beadman, 2002). Both longlines and rafts can increase both primary and secondary production by providing space for algae and fauna to grow on. Such systems also act as nursery areas for fish and this food resource can also provide additional food resources for diving birds (Smaal *et al.,* 2005).

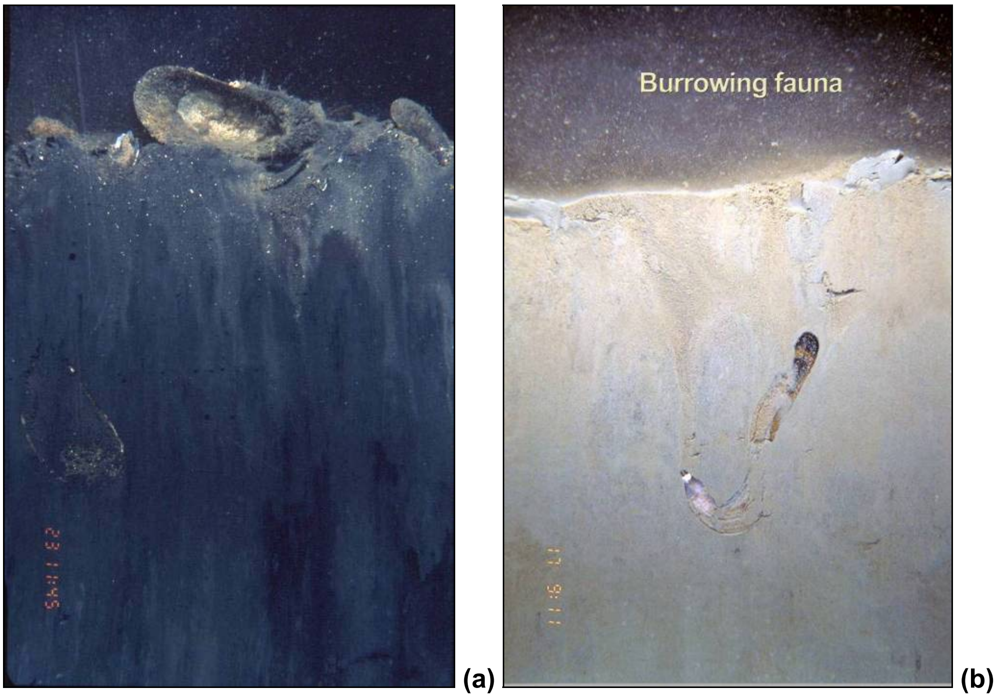

Figure 14. Sediment Profile Image (SPI) of (a) anoxic sediment under an intensive suspended shellfish farm on the west coast of Ireland and (b) unimpacted sediment with burrowing fauna visible. (© AquaFact International Ltd, 2006)

2.5.6 Bottom culture

Re-laid mussel beds compete for space and food and, depending on the degree of intensification, can out-compete the original fauna. If the bottom production is confined to a certain area of a bay or sea inlet, the overall ecosystem can generally cope with the impact. However, where production covers a considerable proportion of a bay, impact on the ecosystem is greater. For the intertidal cultivation of Manila clams (*Tapes philippinarum*) in parcs, some form of habitat modification is usually employed (by adding gravel and crushed shell to the substratum) and protecting the parcs with netting. This can result in a persistent alteration in the species composition of the locality (Kaiser and Beadman, 2002) and feeding and roosting areas for birds can be reduced (Kaiser *et al.*, 1998). However the effect of intertidal culture on bird populations is an understudied area and more research is needed (Kaiser and Beadman, 2002).

2.5.7 Maintaining and harvesting

The maintenance and harvesting of suspended and trestle grown bivalves has little direct impact. However, the harvest of intertidal species cultivated directly on or in the substratum requires various means of mechanical extraction such as the use of tractors and suctions dredges for cockle extraction which removes the entire upper sediment layer and infauna (Kaiser and Beadman, 2002). Turning and grading of shellfish in intertidal mariculture activities requires access and a presence on the foreshore and this can result in a temporary disturbance on feeding birds. In addition, access across the foreshore can result in damage due to compaction from tractors and other vehicles along access routes.

2.6 Impacts of finfish mariculture

As discussed in section 2.2, fish are produced in Salinas in region IV but production quantities are relatively small. Impact from this method of production is localised and on an already highly modified ecosystem. For these reasons, the specific impacts from this method of production will not be considered further.

2.6.1 Transfer of disease

Disease transmission can occur when wild fish interact with caged fish and escaped farmed fish can transfer disease to other culture stocks and wild populations over a wide geographic area. Diseases spread by cultured salmonids include infectious pancreatic necrosis (IPN), infectious salmon anaemia (ISA), viral haemorrhagic septicaemia (VHS) and furunculosis.

The DIPNET project published a comprehensive review of disease interactions and pathogen exchange between farmed and wild finfish and shellfish in Europe in 2007 (DIPNET, 2007). The main conclusions relevant to the OSPAR area are summarised here.

It can be the case that pathogens observed in cultured stocks have increased virulence but they did originate in the wild. The rate at which farmed fish become infected with pathogens of wild origin is unknown although there are cases, for example with ISA, where separate emergence in aquaculture from wild sources is considered to have occurred several times. Although these cases of emergence may be relatively rare, once farmed populations are infected, conditions can lead to widespread infection throughout an industry through movements of live animals. Thus there is often evidence for the first occurrence of a disease in culture being of a wild origin. However, the extent to which future infections are derived from wild or other infected farm animals can be unclear for many cases.

Live fish movements are known to be the greatest risk for introduction and transmission of disease and such live movements are common place in aquaculture.

The review found only a few diseases where there is evidence of pathogen transmission from farmed to wild and even less evidence that this resulted in disease and that there was evidence of detrimental effects. For the finfish viral pathogens, it cannot be concluded with high levels of confidence for any of the disease examined that infection in farmed populations has resulted in disease in wild populations although there is some evidence for transmission for some viruses. The same is true for bacterial pathogens with the exception of historical epidemiological evidence for furunculosis of wild salmonids in Norway.

There is good evidence that some parasites are capable of transmitting from farmed to wild fish and in some cases this may be harmful. The fish parasite *Gyrodactylus salaris* was introduced through restocking and farming practices to rivers in Norway and resulted in large reductions in wild Atlantic salmon population size.

In general, pathogens do not cross phyletic barriers (*i.e.* diseases are not transmissible from finfish to shellfish or vice versa), though bivalves may be mechanical vectors of some fish pathogens.

Viral and bacterial pathogens may evolve increased virulence in the aquaculture environment. Though these virulent pathogens could spill back into wild populations, there is no evidence that virulent strains of diseases such as ISA and IPN impact wild populations. The conditions that promote epizootics and disease outbreaks in aquaculture may be rare in wild fish populations, reducing disease effects in the wild. If host density, genetic diversity and population size limit sustainable transmission in wild fish, then there may be a local effect in situations where large and dense populations occur in the vicinity of fish farms, for example, where shoaling species are close to cages or farm effluent. The location of fish farms could thus be an important factor in interactions between wild and farmed species. Although increased virulence can occur in farms, there are measures that can be taken to reduce this likelihood through disease prevention steps such as good biosecurity.

Differences in immunological diversity may also be present between wild and farmed populations. The suppression of diversity in fish culture may be leading to greater impacts from disease in comparison to the wild populations which are more genetically diverse. However, a natural genetically diverse population may be very susceptible to a pathogen which it has not encountered previously and for which there may be little immunity. This may have contributed to the occurrence of natural outbreaks of furunculosis in Atlantic salmon in the early 20th century in the United Kingdom, with survivors of the epizootics contributing to greater resistance in future generations.

The main source of infection for farmed fish is other farms and there are few diseases where there is sufficient evidence that infected farm populations pose a significant risk of infection to wild populations. However, there are many more diseases for which there is circumstantial evidence or where transmission of infection is suspected and where a potential risk to wild fish exists. For many pathogens transmission can occur locally between farms or over greater distances through live animal movements.

Diseases that do not cause problems for native species in one region can prove highly damaging to different species of host found elsewhere. The information available for individual pathogens often applies to a particular geographic location and it is generally difficult to extrapolate these data to a different location. This is because disease may be dependent on local conditions involving changes in environment and host population size and density.

2.6.2 Parasites

Sea trout (*Salmo trutta* L.) and Atlantic salmon (*S.salar* L.) are hosts for sea lice. The transfer of parasites between farmed and wild fish is a cause for concern (Boxaspen, 2006). The most important sea louse species in salmonid aquaculture in the OSPAR region are *Lepeophtheirus salmonis* (Krøyer) and *Caligus elongatus* (von Nordmann). Due to its larger size and year round presence, *L.salmonis* causes most damage in European Atlantic salmon farms. Damage to the host fish is caused by the sea lice which feed on skin, mucus and blood. Host responses to infestations of sea lice include loss of appetite and reduced growth and changes in the levels of haematological parameters. Skin abrasions followed by osmotic problems, secondary infections and mortality have also been reported (Nolan *et al.*, 1999; Pike and Wadsworth, 1999; Bowers *et al.*, 2000; Finstad *et al.,* 2000; Tully and Nolan, 2002; Heuch *et al.*, 2005).

In Europe, farmed Atlantic salmon now outnumber wild Atlantic salmon by nearly 50:1 (Porter, 2003). Farmed Atlantic salmon cages, where fish are kept in close proximity at high densities, provide an ideal environment for the proliferation of sea lice. As a result, farmed Atlantic salmon are now a major year-round producer of sea lice (mainly *L. salmonis*) in the world's coastal marine waters (Butler, 2002; Heuch *et al.,* 2005; Orr, 2007). Farmed fish hosting small numbers of sea lice per individual can collectively produce large numbers of sea louse eggs (Orr, 2007). Heuch and Mo (2001) estimated that farmed Atlantic salmon in Norwegian waters produced nearly 1.45×10^{11} eggs in 1990 during the critical 2-month (April – May) spring migration of juvenile salmonids.

Environmental conditions such as temperature, salinity, wind and tidal currents affect the development and dispersion of sea lice and these factors vary seasonally and by geographical location. It is important when assessing the contribution that Atlantic salmon farming has on potential sea lice infestation, and the physiological effects that sea lice have on wild salmonid populations that these factors are considered.

Extensive infection with sea lice occurs in inshore waters with the highest levels being found in areas being used for Atlantic salmon farming, particularly when the farms are in the second year of production (MacKenzie *et al.,* 1998; Tully *et al.,* 1999; Butler, 2001; Hatton-Ellis *et al.,* 2006). Although some evidence of temporal and spatial variations in sea louse infestation of farmed and wild salmonids is available, there are no historical data on what were the previous levels of infection in farming areas. Consequently, it is impossible to prove whether or not there have been changes in sea louse infestation levels in wild salmonids since the development of Atlantic salmon farming. However the salmon lice infection in regions of the Norwegian coastline in 2008 was elevated compared to historic levels (Heuch *et al*., 2005, Bjørn *et al.*, 2009). Although environmental factors such as season and salinity affect sea lice infestation, natural variations are masked by variations within and between farms caused by local conditions and farm management practices. Re-infestation within farms is common but fallowing of farm sites between generations of stocks can greatly reduce sea louse numbers.

Interactions between Atlantic salmon farms and wild fish through the transfer of lice from the farms have been the topic of numerous studies and considerable controversy, with *L. salmonis* from farmed fish being implicated in the decline of wild Atlantic salmon and particularly sea trout in areas where Atlantic salmon farms are located (Birkeland and Jakobsen, 1997; Bjørn *et al.*, 2001; Heuch *et al.,* 2005; Krkošěk *et al.,* 2007; Ford and Myers, 2008). In Ireland, references have been made to a possible link between elevated numbers of sea lice (*L. salmonis*) on sea trout and the distance to the nearest Atlantic salmon farm. Although areas of intense Atlantic salmon farming and heavy lice infestations on sea trout are positively associated, there is, as yet, no direct evidence of the role and significance of Atlantic salmon farms in the transmission of sea lice to sea trout (MacKenzie *et al.* 1998).

There has been a tendency to focus on *Lepeophtheirus salmonis* as the most commercially important sea louse. However, the importance of *Caligus elongatus,* a host generalist to salmonids and other finfish (including cod) within the OSPAR region should not be underestimated (Todd, 2007). Gadoid mariculture, especially cod farming is currently expanding rapidly in the North-East Atlantic. In contrast to salmonid culture where transfer of fish between freshwater and seawater represents a barrier to many parasites and pathogens, farming of cod is carried out in seawater and are therefore permanently exposed to disease and parasites that may be in the locality. The wealth of experience and knowledge that has been attained in relation to *L. salmonis* should prove valuable when considering the possible detrimental effects on the stocks of wild gadoid and salmonids that *C. elongatus* may have as cod farming develops (Øines *et al.,* 2006).

2.6.3 Escapes

Mariculture operations (as opposed to closed circulation or land based aquaculture) have the potential to provide an almost continuous supply of escapees into the natural environment. These escapes occur during the day-to-day operations of a fish farm which include stocking, grading and disease treatment, as well as occasional mass releases caused by storm or predator damage of the cage equipment or by construction failure (Beveridge, 1987). In 2002 an estimated 600 000 farmed salmon escaped in a single storm incident in the Faeroe Islands (Atlantic Salmon Federation, 2002). Kavanagh *et al.* (2007) reported that globally, 10.2 million farmed salmonids escaped from open net cages between 2002 and 2006. It is estimated that some two million salmon escape each year in the North Atlantic region (McGinnity *et al.,* 2003), which is approximately 50% of the total pre-fishery abundance of wild salmon in the area (based on Atlantic Salmon Federation data, 2002).

Impacts of escaped farmed salmonids (both salmon and rainbow trout) on wild populations may include transfer of diseases and parasites, competition for wild food resources, competition for spawning habitat and the destruction of wild salmon eggs by the later spawning farmed species which dig up the eggs. The homing precision of escaped farmed salmonids seems to be less accurate than their wild counterparts (Jonsson *et al.,* 2003) and many cultured salmonids may reproduce or attempt to reproduce in rivers over a relatively wide geographical area, thus spreading the impact even further. Farmed salmon are lost to the surrounding environment through damage to the nets, during routine handling, for example, grading, treatments, and the transfer of fish to or between cages and at harvesting, or as the result of vandalism. Escaped adult salmon may breed with other escapees and wild salmon thus posing a risk to wild stocks (Walker *et al.*, 2006).

The contribution of farmed and ranched salmon to national catches in the North-East Atlantic area in 2007 was generally low (<2% in most countries) and is similar to the values that have been reported previously by ICES. The occurrence of such fish is usually ignored in assessments of the status of national stocks. However, in Norway farmed salmon continue to form a large proportion of the catch in coastal (29% in 2007), fjordic (30% in 2007) and rod fisheries (9% in 2007) (ICES, 2008), and the average proportion of farmed salmon in the spawning stocks in 2007 was 14% (Hansen *et al*., 2008). There is evidence to suggest that freshwater escapes from hatcheries are of main concern (ICES, 2002). According to WWF, about 50% of the world's population of wild Atlantic salmon spawns in Norwegian rivers (Esmark *et al*., 2005). The main risk from escaped fish could be due to displacement of wild fish, loss of production and direct genetic intrusion. In Norway, recovery of the wild population is not likely under any circumstance, even after many decades during which no further intrusions occur (Hindar and Diserud, 2007).

2.6.4 Genetic impacts

Most of the data currently available on the impacts of finfish escapes on the environment come from work on salmonids. Farmed salmon are selectively bred for rapid growth, taste, fat content and resistance to disease. As a result of this they are genetically distinct from their wild counterparts and tend to lack the genetic variability for adaptability and long-term survival and have a reduced reproductive capacity in the wild. The increase of Atlantic salmon culture in the OSPAR region to almost 780 000 tonnes in 2006 (FAO, 2008) has meant that large scale escapes are now frequent occurrences.

Although their breeding performance has been shown to be inferior to that of wild salmon (Fleming *et al.* 1996, 2000), escaped farm salmon do breed successfully and hybridise with wild fish (Lura and Sægrov, 1991; Crozier 1993, 2000; Clifford *et al.* 1998), thereby potentially changing the genetic make-up, fitness (*i.e.* juvenile recruitment in subsequent generations) and life-history characteristics (for example, age and timing of maturity and spawning) of wild populations.

Wild salmon stocks vary genetically between rivers and there is a relatively low rate of interbreeding between populations as they return to their river of origin to breed. Cultured salmon have reduced homing abilities and the interbreeding of wild salmon with escaped cultured salmon that have no attachment to a particular river can reduce local adaptation and can impact the viability and character of the stock with the result that the hybrid offspring have a lower survival rate (McGinnity *et al.*, 2003).

It is thought that there would be less impact on genetic diversity of wild fish by escapees if cultured stock was not produced entirely from domesticated strains. However, the use of wild fish in combination with domesticated strains will put an alternative undesired pressure on the wild stock by promoting capture of wild organisms. More research is required to strike the right balance to preserve genetic diversity (CBD, 2004).

In addition to these direct genetic effects, indirect genetic effects occur when there are ecological or disease interactions between released or escaped cultured strains and wild populations, resulting in drastic reductions in the size of wild populations (Davenport *et al.*, 2003). The reduced population may then become susceptible to a number of potentially detrimental genetic effects.

Because natural populations of Atlantic salmon are a major resource for angling, tourism and commercial exploitation, as well as being an important component of biodiversity with cultural and aesthetic significance, these intrusions of farmed fish into wild populations are of increasing concern. This is particularly the case in recent years as stocks have been declined in both Europe and North America thought to be related to poor sea survival, (International Atlantic Salmon Research Board, 2009). While the addition of farmed escapees may be seen as superficially beneficial from the point of view of angling (larger quantities of fish available to be caught), the long-term effects of escapees would be detrimental to the wild populations.

It is common practice to transfer broodstock, ova and fry between different mariculture regions throughout the world. This could have an impact on the biodiversity of these regions through the introduction of diseases, parasites and non-native species. In the OSPAR maritime area such practices are strictly regulated and only health, disease free fish are permitted for transfer.

Case Study: Cod farming

Some of the world's cod stocks are in a dramatic decline and cod is on the OSPAR list of Threatened and/or Declining Species in OSPAR Regions II and III. In 1970, the total global catch of cod was 3.1 million tonnes while in 2006 the total catch was down to 836 000 tonnes, a reduction of over 70% (FAO, 2008). Farming of cod is seen as a means to supply the demand for cod while reducing the impact on vulnerable wild cod stock. Cod farming in the OSPAR region in 2006 produced 13 200 tonnes with Norway producing over 11 000 tonnes of this. Farmed cod have not been bred in captivity as long as salmon and the differences between cultured and wild cod are probably not yet significant. Nonetheless, escapes of farmed cod into the wild will have an impact on the environment.

WWF have expressed concerns that the growing cod farming industry will bring problems to a declining and vulnerable wild cod population such as disease and parasite transfer, displacement at spawning grounds of wild fish by escapees and could result in interbreeding and reduced survival rate (Esmark *et al.*, 2005). Cod behave differently in cages than salmon and are ten times more likely to escape (Fiskeriforskning, 2004). In 2006 alone, 290 000 cod escaped from farms in Norway (Svåsand *et al.*, 2007). Kavanagh *et al.* (2007) calculated the 2006 escape ratio of farmed cod in Norway as 1:12 (escape ratios of other marine species such as Arctic charr, halibut and turbot was 1:50 and for salmon 1:300). Prevention of escape must be achieved through technical changes, adapted surveillance and increased knowledge about the cod's behaviour in cages (Fiskeriforskning, 2005).

Farmed cod are reared exclusively in a marine environment. Harvesting is usually carried out in the third or fourth year of the fish's life and, as cod can reach sexual maturity at one and a half to two years, the release of gametes into the environment is inevitable. Farm locations with water currents greater than 1m/s are unsuitable for cod farming and so farms tend to be situated in nearshore sheltered regions. As Atlantic cod typically aggregate offshore for spawning, the dominant interactions between cultured and wild cod will be via escapes of cod from cages rather than via dispersal of gametes (GESAMP, 2008). A pilot experiment performed in the Heimarkspollen in Austevoll, Norway, has demonstrated that farmed cod are capable of producing viable cod larvae that mix with wild larvae in the area,(The Institute of Marine Research, www.imr.no). At present the genetic differences between farmed and wild cod in new cod farming areas like Scotland are small. The more generations of cultured cod undergo domestication selection, the more likely they are to contribute gene complexes that are maladapted to the wild (Bekkevold *et al.,* 2006). Further research is required to assess the likely fitness of hybrids formed by the interbreeding of wild and farmed fish, and of the consequences of any reduction in fitness for local and more widespread populations. The release of genetic material from cod farms (either in the form of gametes or escaped fish) could be minimised by harvesting fish before they reach maturity or through the use of sterile fish or using land-based facilities where effluent can be filtered. The maintenance of sufficiently large wild cod populations may be an efficient tool to mitigate against the introgression of farmed cod genes (GESAMP, 2008).

2.6.5 Effect of organic wastes on the sea floor

Organic enrichment can result from intensive aquaculture activities. Due to high settling velocities of uneaten pellets, much of this material settles out in the immediate vicinity of fish cages. The area of the seabed over which the material will be dispersed will depend on the surface area of the farm, the settling velocity of the uneaten food and faeces, current speeds and the depth of water beneath the cage. Two zones result:

- an inner zone which receives uneaten food and faeces, and
- an outer zone receiving faecal waste only.

This is shown in generalised way in Figure 15. Although loadings beneath fish farms can be high, the scale of effect is, in most cases, localised and restricted to the immediate vicinity of the farm. This effect is usually limited to within 20 metres of the cages. Where current velocities are high the impact on the benthos in the vicinity of the farm may not be discernible.

High sedimentation rates can result in modifications to the sediment chemistry and animal populations beneath farms. On deposition, organic materials begin to breakdown and form a source of nutrient inputs for the natural fauna both within the sediments and the overlying water column. On, and within, the sediments aerobic respiration and other oxygen dependent microbial processes fuelled by the waste, impose extra oxygen demands on the system. Bacterial decomposition of organic material within the sediment can lead to a lowering of redox potential (the depth in the sediments to which oxygen is present) as oxygen is consumed.

In conditions where oxygen is limited within the sediments hydrogen sulphide, ammonium and methane are generated. Ammonia is soluble and will dissolve in the overlying water where, in addition to the by-products of fish excretion, it contributes to the total soluble nitrogenous wastes produced. Hydrogen sulphide is slightly soluble and methane is insoluble in water. In extreme cases, these gases, but mainly methane, can contribute to outgassing from the sediments in the vicinity of the cages. Each of these reduced compounds is toxic to fish and other organisms.

The effects of mariculture organic wastes on bottom living animals are similar to those associated with other inputs of organic matter, for example, sewage waste. Under high input loadings there may be a loss of sensitive species and an increase in the biomass of more tolerant organisms. Moving away from the source of inputs or under conditions of moderate loadings, there is an enhancement of the natural productivity of the local fauna. Further away or under conditions of low organic inputs, the natural fauna are unaffected.

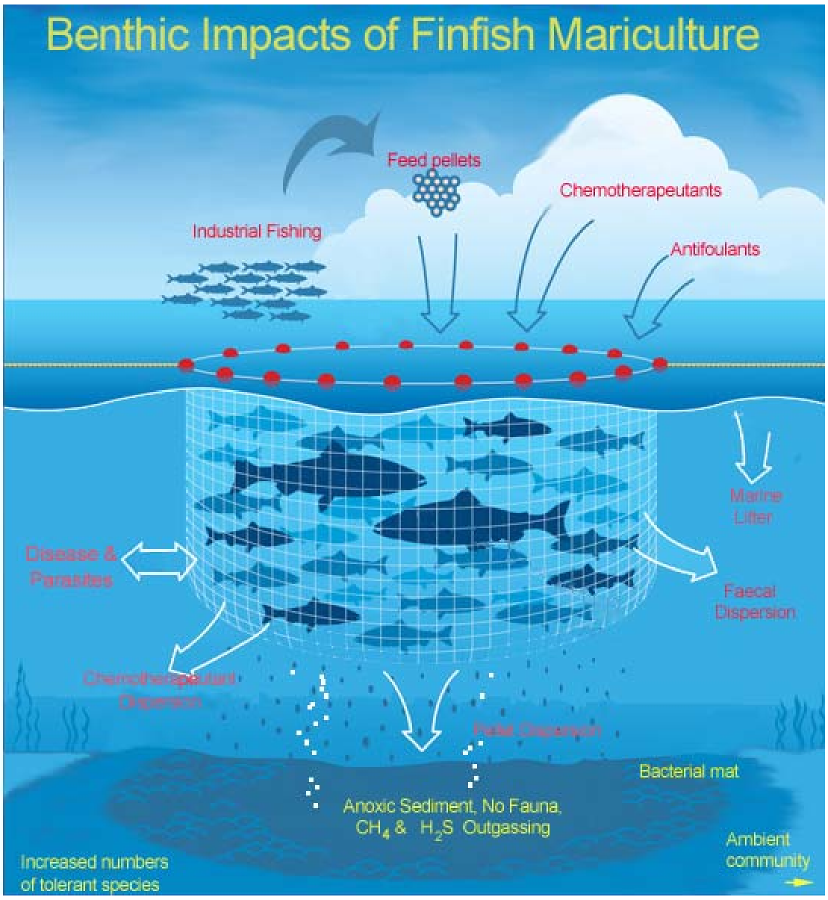

Figure 15. Benthic Impacts of Finfish mariculture (Adapted from Pew Oceans Commission)

The infaunal macrofauna, *i.e.* the larger animals such as bristleworms, shellfish and starfish which live in the sediment on the seafloor under salmon farms react to the input of organic material in a variety of ways. If enrichment rates are high, the sediments under the cages may be devoid of any larger infaunal animals such as sea potatoes (*Echinocardium*), sea cucumbers (*Leptopentacta*) and deep burrowing shrimps

(*Upogebia*) and a variety of large worms all of which re-work the upper 5 – 10 cm of sediment, using up its organic load and helping to maintain relatively high levels of oxygen within the sediment. This activity is known as bioturbation. Once these relatively long living and slow recruiting species are gone, it can take a number of years for them to re-establish.

If inputs of organic carbon to the sea floor are somewhat lower, high densities of such opportunistic worm species as *Capitella capitata* (complex) or *Malacoceros fuliginosus* occur. These are small species which are short lived and do not have the same capacity to bioturbate. They are also adapted to living in hypoxic (low oxygen) or anoxic (no oxygen) sediments. In fact, these species are so efficient at degrading organic matter that they have been added to organically enriched sediment beneath fish farm cages in Japan to enhance the decomposition rates (Kinoshita *et al.,* 2008; Wada *et al.,* 2007). The Environmental Protection Agency in Ireland is currently funding research on the use polychaete worms in the bioremediation of organically rich sediments under fish farm cages. These methods are promising developments for minimisation of the negative effects of fish farms have on the benthos. A feature of organically enriched sediments, common in low velocity locations, is the presence of grey or whitish bacterial mats of *Beggiatoa* sp which live on the sediment surface and can occur as discrete patches or as larger blankets. Such bacteria require some level of oxygen and it may be misleading to assume that the absence of *Beggiatoa* sp. on black sediment indicates a healthy environment. Some mobile and epibenthic species, for example star fish (*Asterias*) and crabs (*Liocarcinus*) and some fish species such as pollack increase in numbers around salmon farms, a response to the availability of food in the form of uneaten pellets. However, feeding on pellets (especially the high fat content foods adapted for salmon) can lead to physical changes have (enlarged liver and changes in shape and texture) in pollack caught close to fish farms.

Although salmon cages are sources of organic enrichment, such systems can be managed to avoid over enrichment. The natural environment has an inbuilt capacity to incorporate and recycle organic matter; however, there is a limit to this assimilation capacity. A major goal of aquaculture is to keep the organic load within the natural system's ability to recycle and assimilate it. In cage aquaculture, uneaten fish feed is one of the main organic loads. Feed can cost up to 40% of the total production cost so fish farmers strive to reduce the amount of feed wasted. Feeding is usually carefully regulated to ensure that the maximum amount of food is taken up directly by the captive fish. Feeding regimes (rations size, feeding frequency, and time of day of feeding) are important in determining the amount of feed lost (Islam, 2005). Improvements in feed such as pellets that either float or to sink slowly through the water help to reduce the waste (see section 4.3). Fish mortalities are another source of organic enrichment of sediments under cages and fish deaths should be monitored and carcasses removed. Other management options relate to site selection, minor cage movements and fallowing sites for shorter or longer periods of time.

Benthic communities may return to close to pre-impact conditions once the source of organic enrichment has been removed (Pearson and Rosenberg, 1978) *i.e.* with the introduction of fallow periods. The rate of return is site-specific but typically rates of up to 1 year are suggested for recovery under fish farms.

2.6.6 Impact of Nutrients on water quality

Nutrient enrichment can result from the input of excessive quantities of soluble organic matter and its consequences, including enhanced phytoplankton production, are complex (Gowen and Bradbury, 1987). Nitrogen tends to be the factor limiting phytoplankton growth in seawater. However, several other growth factors may restrict the utilisation of additional nitrogen by phytoplankton (for example, light, turbulence, hydrographic characteristics such as flushing and residence times etc.).

One possible consequence of nutrient enrichment is the alteration of the species composition of the phytoplankton with a possible danger of the proliferation of potentially toxic or nuisance species. The effects of fish farm wastes on seaweeds are poorly understood but it may be expected that with increased levels of nutrients close to the cages some species may increase in biomass. Increased sedimentation and/ or reduced light penetration may have negative effects on macroalgae.

Little detectable increase has been shown in phytoplankton standing crop adjacent to cages in European and American waters (Weston, 1990; Gowen, 1990; Gubbins *et al*., 2003) even though there are increases in ammonia. The reasons for this may be due to algal growth and water exchange rates where salmon farming occurs.

Toxic phytoplankton blooms have been responsible for mortalities of wild and farmed fish in Scotland, Norway and Ireland (OSPAR Regions II and III) but the relationship between the occurrence of blooms and the location of fish farms has not been proven. A Scottish review on the relationship between fish farms and harmful algal blooms (Smayda, 2006) indicated that increased nutrient loading from fish farm wastes in Scotland had not been accompanied by a detectable increase in blooms within Scottish waters. Shellfish cultivation was found both to stimulate and inhibit the growth of phytoplankton species.

The growing aquaculture industry has become a relevant point source of nutrients in some Contracting Parties. To assist Contracting Parties identify areas where nutrient inputs are likely, directly or indirectly, to cause pollution, marine areas are characterized by the Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area (the “Common Procedure”), adopted by OSPAR in 1997 and revised in 2005. The Common Procedure characterises the quality of the marine environment with regard to eutrophication in terms of problem areas, potential problem areas and non-problem areas (OSPAR, 2005). Following a first application of the Common Procedure in 2002 – 2003 (OSPAR, 2003), the second assessment in 2007 - 2008 covered the period 2001 – 2005 and concluded that eutrophication is still a problem in 106 areas of the North-East Atlantic, Figure 16 (OSPAR, 2008a).

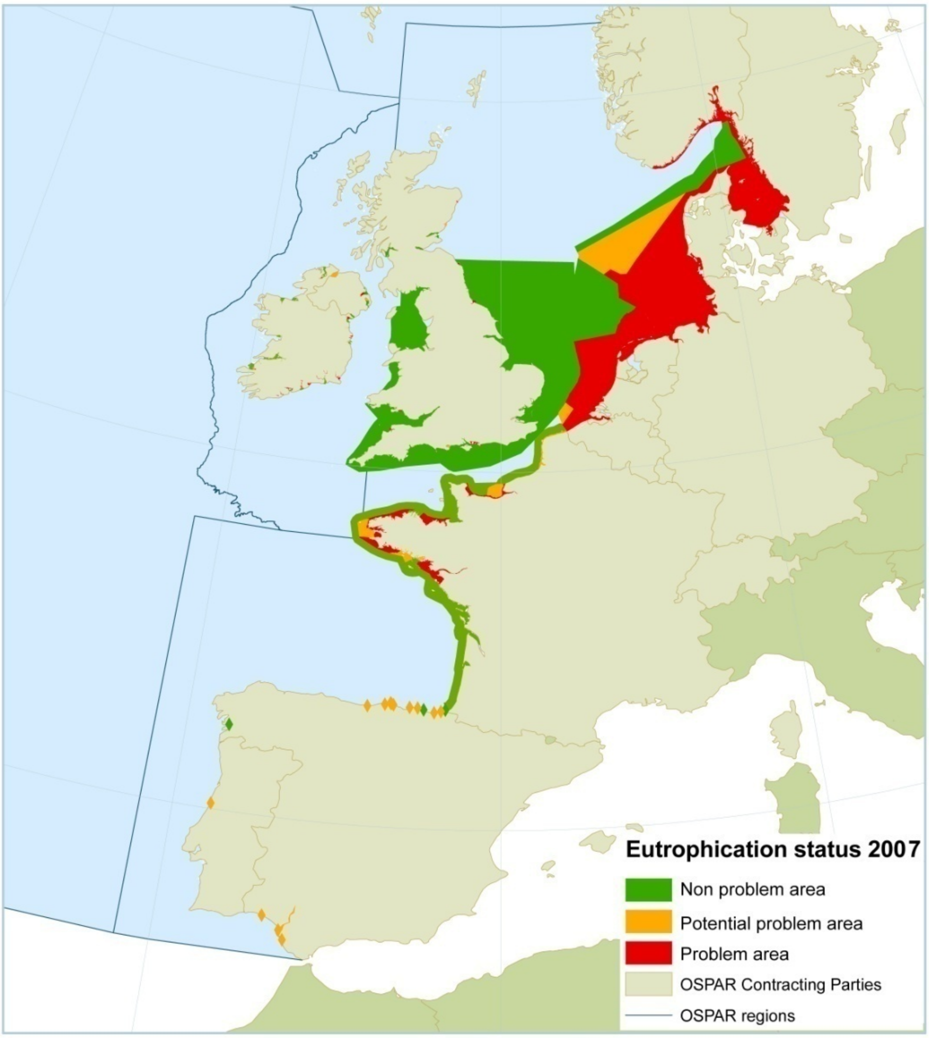

Figure 16. Eutrophication status of the OSPAR maritime area assessed in 2007 (Source: OSPAR, 2008a)

A visual comparison of problem and potential problem areas (Figure 16) with finfish mariculture intensity (Figure 12) indicates that in general finfish mariculture occurs in areas that are not seen to be problematic in terms of nutrients. In problem or potential problem areas assessed under the Common Procedure, the contribution of aquaculture is considered to be negligible compared to other sources, as shown in Figure 17. In Norway, the discharges of nitrogen and phosphorus into the Skagerrak have increased between 1985 and 2005, but in this area the production of aquaculture is limited. The discharges of nitrogen and phosphorus from aquaculture in Norway to the area outside the problem-area (Skagerrak) are increasing and the discharges to the North and Norwegian Seas constitute a major part of these discharges. The precise level of local impact will vary according to production scale and techniques as well as the hydrodynamic and chemical characteristics of the region (EEA, 2009).

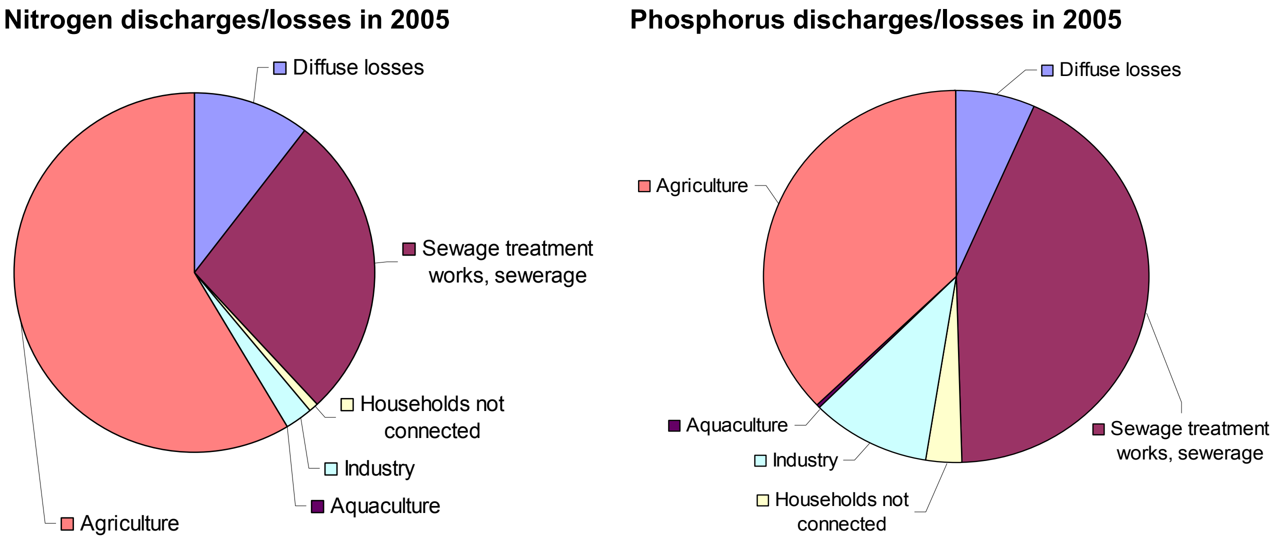

Figure 17. Contribution of the different anthropogenic sources to the total losses and discharges of nutrients in 2005 (Source: OSPAR, 2008b)

2.6.7 Oxygen depletion in the water column

Oxygen consumption by fish and microbial activity can lower oxygen concentrations in the water column. Consumption is variable and relates to fish biomass, the season and the physical characteristics of the site. Oxygen reductions can be increased by the settlement of algae, hydrozoans, bryozoans and tunicates on the nets. Studies of the environmental impacts of cage aquaculture on the water column have shown an increase in the levels of suspended solids and nutrients, and a decrease in dissolved oxygen levels around cages (Hargrave *et al.,* 1993; Islam, 2005). Measurements of oxygen within and close to salmon cages show reductions of up to 2.0 mg/l compared to control sites (AQUAFACT International, unpublished reports). Site selection and stocking density are the main mitigating measures against oxygen depletion and, where it does occur, it is localised.

2.6.8 Case Study

Monitoring of Scottish sea lochs for the effects of nutrients from fish farms – Case Study

The majority of United Kingdom marine fish farming takes place in the sheltered waters of sea lochs, and voes, of the west coast, Western and Northern Isles of Scotland. Nutrient discharges from fish farms in these semi-enclosed waters have the potential to result in nutrient enhancement. In order to assess the potential eutrophication status of these regions the United Kingdom undertook an extensive programme of monitoring and assessment between 2002 and 2006 covering some 38 water bodies supporting fish farms (Figure 1). Hotspot areas were targeted for the assessment, where according to simple models relating nitrogen discharge rates from fish farms to flushing rates of sea lochs, nitrogen enhancement was predicted to be highest.

These areas were monitored at key times of the year and parameters monitored according to the OSPAR Comprehensive Procedure (COMPP) and assessed against the Harmonised Assessment Criteria.

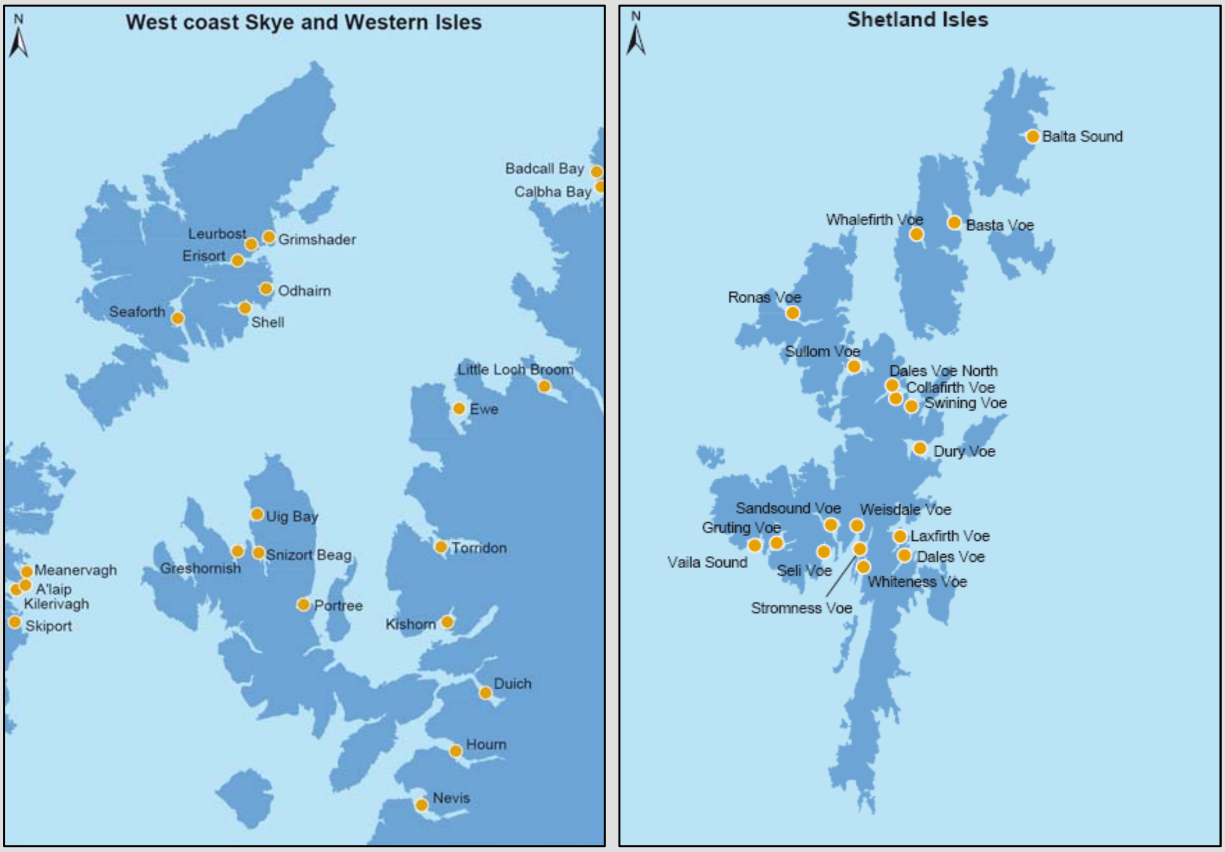

Figure. Sea lochs, voes, sounds and bays monitored by Fisheries Research Services during 2002 – 2006 and assessed as ‘Non Problem Areas’ with respect to the effects of nutrients from fish farms by applying the OSPAR Comprehensive Procedure for eutrophication assessment.

An overall assessment of the parameters according to the COMPP was undertaken and resulted in Non-Problem Area classifications for all the sea lochs assessed with respect to nutrient inputs from aquaculture. A summary of results is shown in Table A.

Table A: Summary of the application of COMPP and Harmonised Assessment Criteria to 38 Scottish sea lochs supporting aquaculture.

Assessment Parameter	**Summary of findings for Scottish sea lochs**
Category I	***Degree of nutrient enrichment***
1 Nutrient inputs	In general, nutrient inputs from aquaculture decreased from 2003 – 2005 across Scotland as feeding efficiency improves and production declined over this period. Regulatory restrictions will prevent future increases in nutrient discharges from aquaculture in most hotspot areas.
2 Nutrient concentrations	Winter nutrient (DAIN) concentrations did not exceed the criteria of 50% above background concentrations of coastal waters for any lochs
3 Nutrient ratios	Winter N/P ratios did not exceed 50% above background values (16) for any sea lochs.
Category II	***Direct effects of nutrient enrichment***
1 Chlorophyll a concentrations	The 90th percentile of measured values did not exceed 50% above background values for coastal waters at any of the sea lochs surveyed.
2 Phytoplankton indicator species	Potentially toxic and nuisance species were recorded at several lochs at densities typical for Scottish waters. The occurrence of these species is not thought to be related to nutrient inputs from aquaculture.
3 Macrophytes and macroalgae	Percentage area coverage of “nuisance” green macroalgae in the intertidal zone did not exceed the assessment level of 15% at any of the sea lochs surveyed.
Category III	***Indirect effects of nutrient enrichment***
1 Oxygen deficiency	The 5th percentile of measured values never fell below the assessment level of 4 mg/l. Some bottom waters in sea loch basins showed lower values which are a result of the natural hydrography of the lochs and are not caused by nutrients from aquaculture.
2 Fish kills	There are occasional kills of farmed fish caused by jellyfish and harmful phytoplankton in sea lochs. These are not related to eutrophic conditions.
3 Organic carbon	Organic carbon levels in sediments vary naturally with hydrography and are high close to fish farms. Levels are not of concern with respect to eutrophication assessment.
Category IV	***Other effects of nutrient enrichment***
1 Algal toxins	Extensive monitoring reported the presence of amnesic, paralytic and lipophilic shellfish toxins in water, plankton and shellfish from several sea lochs. The occurrence of these toxins is typical for Scottish waters and not thought to be related to nutrient inputs from aquaculture.

2.7 Impact of therapeutants and persistent contaminants

The amount of chemicals used in shellfish mariculture is negligible and for the purposes of this assessment will not be considered further. No OSPAR chemicals for priority action or priority action substances in the EU (Water Framework Directive Annex X) are directly used in aquaculture (Marine Institute, 2007). Antibacterial, antifungal and antiparasitic treatments (for example, against sea lice) are the most commonly used medicinal treatments. The increased use of vaccines has significantly reduced the use of antibiotics in mariculture since the 1980s and ongoing developments have allowed this to be maintained over the past 10 years. Management strategies to prevent and reduce the infestation of sea lice, such as synchronous treatments of adjacent farms and fallowing sites to prevent inter-generational transfer of sea lice, can result in a reduction in the use of chemical therapeutants per tonne of fish produced.

Feed is also a potential source of other additives and contaminants. Persistent compounds, such as PCBs, have been detected in the fish oil/fish meal used in feed. This has resulted in the redistribution of these contaminants in the marine environment. In a study undertaken in 2001 – 2002, the Scottish Environmental Protection Agency found concentrations of PCBs in sediments collected in areas close to marine fish farm cages in the range 0.45 to 34.3µg/kg (SEPA, 2005). The report indicated that the majority of sites would be considered “slightly contaminated” but below “probable biological effects” levels. The use of tributyltin (TBT) has not been permitted on aquaculture installations for over 20 years. Where antifoulants are used to prevent fouling of cages they are usually, copper (less commonly zinc) based. Antifoulants are not always used and mechanical cleaning of nets/equipment is often preferred.

The active ingredients of chemicals used in finfish mariculture, method of use and information available on quantities used in Ireland, Norway and United Kingdom are shown in Table 5. Appendix 2 provides the environmental toxicity information of the most commonly used chemicals used in finfish aquaculture. Commonly used methods for managing the impacts of chemicals, including mariculture chemicals, released into the environment is to compare the predicted environmental concentration (PEC) with the predicted no effect concentration (PNEC) used in Norway (SFT, 2007a) or the use of emissions limits to maintain environmental quality standards and environmental objectives as used under the Water Framework Directive (EC, 2000).

Based on the current state of knowledge and monitoring requirements, emamectin has the highest risk quotient because of the very low PNEC (*i.e.* high toxicity). Other mariculture chemicals with potential environmental effects include deltamethrin, praziquantel, cypermethrin and oxolinic acid. In Scotland environmental quality objectives (EQOs) are used to assess the impact of mariculture (SEPA, 2006) and discharges are controlled to ensure the PEC does not exceed the EQO. Information on risk quotient and EQO used in Norway and Scotland are shown in Table 6.

Table 5. Annual chemical usage in finfish mariculture in the OSPAR Maritime Area for the most recent year data is available. Sources: OSPAR, 2006a; SFT, 2007b.

Active Ingredient	**Treatment**	**Treatment Method**	**Quantity (l or kg unless noted)**		
			Ireland 2006	**Norway 2004**	United Kingdom **2004**
Azamethiphos	Sea lice	Bath		0	7.3
Deltamethrin	Sea lice	Bath	3.26	17	Not authorised
Teflubenzuron	Sea lice	Feed	177	0	0
Cypermethrin	Sea lice	Bath	0.04	55	37
Florfenciol	Antibiotic	Feed	6.2	111	6.0
Oxytetracycline hydrochloride	Antibiotic	Feed	1264.5	9	38
Oxolinic acid	Antibiotic	Feed		1035	
Flumequine	Antibiotic	Feed		4	
Tricaine methane sulphonate	Anaesthetic	Bath	1264.5		22.8
Bronopol	Bactericides	Bath	12.5	314	
Emamectin benzoate	Sea lice	Feed	6.39	32	52.1
Fenbendazole	Internal parasites	Feed		23	7.1
Praziquantel	Internal parasites	Feed		412	
Benzocaine	Anaesthetic	Bath		500	25.4
Metacaine	Anaesthetic	Bath		737	
Trimethoprim and sulphadiazine	Antibiotic	Feed	0	0	
Iodine, phosphoric, sulphuric and orthophosphoric acids	Disinfectants	NA	1.8		66 m^3
Hydrogen peroxide	Disinfectants	NA	525		14 600 m^3
Sodium hydroxide	Disinfectants	NA	0		
Pentapotassium bis (peroxymonosulphate) bis (sulphate)	Disinfectants	NA	10		
Metals Zinc / Copper	Antifoulants	Net dip	454 t		

Table 6. Risk quotient applied in Norway and EQS applied in Scotland for assessing impacts of chemicals used in the mariculture industry. Source: SFT, 2007a

Compound	Norwegian PNEC (µg/l)	Scotland EQS
Emamectin	0.00022	0.763 ug/kg dry weight averaged over top 5cm of core applied as a maximum allowable concentration outside the allowable zone of affects. AND 0.22 ng/l as maximum allowable concentration in receiving water body
Deltamethrin	0.00024	6 ng/l 6 hours post-release
Praziquantel	0.028	
Cypermethrin	0.016	16 ng/l 6 h post-release (within dispersion zone)
Oxolinic acid	0.42	
Fenbendazole	0.027	
Bronopol	5.90	
Flumequine	1.59	
Benzocaine	210	
Malachite green	0.66	
Isoeugenol	75.00	
Azamethiphos		40 ng/l 72 h post-release (except in dispersion zone)
Teflubenzuron		5 ng/l annual average in receiving water body and 2.0 µg/kg dry weight averaged over top 5cm of core applied as a maximum allowable concentration outside the allowable zone of effects
Diflubenzuron		5 ng/l annual average within receiving water body
Copper		5 µg/l dissolved, annual mean
Zinc		40 µg/l dissolved, annual mean

3. What has been done?

3.1 Regulation and Best Environmental Practice in mariculture

The environmental impacts of mariculture include impacts related to nutrient loading (uneaten feed and food leachate), feed sourcing (resource extraction for fish meal and fish oil), chemical use (therapeutants, antifoulants, disinfectants and feed additives), escapees (genetic impact on wild populations) and the potential for disease and parasite transfer (EEA, 2007). These impacts are directly relevant under the OSPAR Eutrophication, Hazardous Substances and Biological Diversity and Ecosystem Strategies (OSPAR, 2006b).

The environmental impacts of mariculture within the EU countries of OSPAR are regulated and managed at a European level by several Directives. These include the Dangerous Substance Directive (Council Directive No. 2006/11/EC), the Quality of Shellfish Growing Waters Directive (Council Directive No. 2006/113/EC), the Environmental Impact Assessment Directive, the Strategic Environmental Assessment Directive, Water Framework Directive (Commission Directive No. 2000/60/EC), the EC Nitrates directive (Council Directive No. 91/676/EEC), the Wild Birds Directive, the Species and Habitat Directive. As of 1 August 2008, Council Directive No. 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) governs all aspects of cultured fish welfare within the EU.

As new species continue to be introduced to supply the needs of the market, procedures have been developed to assess the risks and benefits associated with the introduction of alien species. Assessments are governed by codes of practice that have been developed by the ICES, the Convention on Biological Diversity and the FAO Code of Conduct for responsible fisheries. International risk assessment protocols (such as IMPASSE – 'Protocols for assessing the risks of using alien species in aquaculture' assess the potential invasive-ness of species based on four principal modules (pathway/delivery, facility, organism and receptor ecosystem) (ICES, 2008). Strict adherence to the Codes of Practice (ICES, 2004) significantly reduced the number of alien species introduced during the transport of bivalve seed. Within the EC, Council

Regulation No. 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture established measures intended to limit the environmental risks related to movements of non-native aquatic species. The measures include the requirement to obtain a permit in order to undertake such movement, preventive measures such as quarantine, and monitoring measures.

Specifically in the OSPAR area, PARCOM Recommendation 94/6 on "Best Environmental Practice for the Reduction of Inputs of Potentially Toxic Chemicals from Aquaculture Use" is an important measure aimed at reducing the amount of chemicals employed in the industry (medicines, antifoulants, pesticides etc.) and to limit their impact on the marine environment. The Recommendation invites Contracting Parties to draw up codes of best environmental practice and action programmes for the reduction of inputs of chemicals to the sea from aquaculture. No Contracting Party has yet drawn up specific national practice for the reduction of inputs of potentially toxic chemicals from aquaculture. This is probably due to the fact that the main issues are sufficiently covered by existing EC legislation and corresponding national implementing laws and regulations. From 1994 – 2005, Contracting Parties have reported a decline in the use of veterinary medicines on salmon while reporting an increase in salmon production in the same period (OSPAR, 2006c). In order to minimise the amount of medicine used in their finfish aquaculture, Norway successfully utilises cleaner fish, active vaccination programmes, better hygiene routines and strategic delousing programmes (OSPAR, 2006c). Directive 2002/62/EC has effectively banned the use of TBT as an antifoulant on cages, floats, nets and other appliances and equipment used for fish and shellfish culture.

On PARCOM Recommendation 88/2 and 89/4 on the Co-ordinated Programme for the Reduction of Nutrients, the main action in various Contracting Parties with regard to mariculture has been the implementation of the EC water Framework Directive and the Nitrates Directive. In addition to this Norwegian mariculture, which mainly takes place outside the Norwegian OSPAR Eutrophication problem area, have established limits of 100 tonnes nitrogen and 26 tonnes phosphorus on the Skagerrak coast and no new permits for aquaculture will be given within this area if the limits are exceeded, (OSPAR, 2006d). A Norwegian standard, NS 9410 "Guidelines for environmental monitoring of marine fish farms" has been adopted. Denmark is the only CP to have achieved the 50% reduction targets for both nitrogen and phosphorus under PARCOM 94/6 (OSPAR, 2006d).

In addition, general commitments under OSPAR and other international conventions such as Convention on Biodiversity, CITES and UNCLOS apply to aquaculture activities. In particular, the Food and Agriculture Organisation (FAO) of the United Nations adopted a Code of Conduct for Responsible Fisheries in 1995 and was expanded to include aquaculture practices in 1997. This provides guidelines for the sustainable and responsible development of the fishing industry. It provided best available methods for reduction of pollution from mariculture, as well as husbandry, optimal feeding regimes, environmental responsibility and animal welfare (Fernandes *et al.,* 2002).

OSPAR Contracting Parties are also members of the North Atlantic Salmon Conservation Organisation (NASCO) and have signed the Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimise Impacts from Aquaculture, Introductions and Transfers, and Transgenic on Wild Salmon Stocks (NASCO, 2003).

In the EC, a company that wishes to bring a veterinary medicine to the market may submit a single application to the European Medicines Agency (EMEA) for a 'marketing authorisation' (licence) that is valid simultaneously in all EU Member States, plus Iceland, Liechtenstein and Norway. All medicinal products for human and animal use, including mariculture, derived from biotechnology and other high technology processes, must be approved via the centralised procedure. Environmental effects as well as food safety are important consideration in this approval process. The requirement to carry out an assessment of the environment safety of any veterinary medicinal product was introduced by Directive 92/18/EC. Directive 2001/82/EC as amended by Directive 2004/28/EC and Regulation (EC) 726/2004 introduced mandatory risk assessments for assessment for all new and renewal authorisations for medicines used in mariculture. A series of guidelines have been issued by EMEA (2007) and the European Communities (EC, 2003) on assessing the risk of veterinary medicines used or discharged to the marine environment. In 2008 the

Hazardous Substance Committee of OSPAR concluded that in the case of veterinary medicines applications in aquaculture, the testing required under the existing EC legislation and EMEA guidelines (provided their recommendations are fully implemented) are likely to reveal if a substance gives rise to high concern for human health or the environment (HSC, 2008).

Self-regulation is important for the aquaculture industry and the Federation of European Aquaculture Producers (FEAP) has established a code of conduct which includes Codes of Practice, Management Schemes, Quality Schemes and labelling and certification schemes. The FEAPs CONSENSUS project established a code of conduct for sustainable aquaculture and a list of specific indicators which can be used to measure progress towards sustainability. These indicators include economic viability, public image, resource use, health and welfare, environmental standards, human resources, biodiversity, post-harvest and sectoral issues (see http://www.aquamedia.info/consensus/). In addition, Contracting Parties may have their own codes of practice such as Scotland's 'A Code of Good Practice for Finfish Aquaculture' (http://www.scottishsalmon.co.uk/dlDocs/CoGp.pdf). Such initiatives undertaken by the industry itself are steering aquaculture towards more environmentally sound practices.

3.2 Technology and Management Improvements in Mariculture

In order to mitigate against the environmental impacts of mariculture, a concerted action among public and private sectors is required. Several initiatives and advances in environmental management are being employed.

On an individual farm basis, these include the following measures:

- Increased use of fallowing (leaving a site with no production for a reasonable length of time) gives the local ecosystem the opportunity to assimilate accumulated organic matter and to restore the location to its initial conditions. At the same time, this procedure breaks the life cycles of potential pathogen organisms such as sea lice and contributes to securing a healthy status on the next generation of fish at that site (IUCN, 2007).
- improved cage design, including the development of a high strength, lightweight polyethylene fibre that has twice the strength of typical aquaculture nets minimises the escape of farmed fish.
- Within the past two decades the percentage of dietary fishmeal and fish oil used within salmon feeds has changed dramatically, with fishmeal inclusion levels decreasing from an average level of 60% in 1985, 50% in 1990, 45% in 1995, 40% in 2000, to the present level of around 35% (Tacon, 2005). while this decrease in fishmeal has been accompanied by an equivalent increase in dietary fish oils (increasing from a low of 10% in 1985 to a high of 35 – 40% in 2005, there have also been moves towards improved feed conversion efficiency through husbandry and feed formulation.
- There has been an increased efficiency in use of medications and reduced use of antibiotics including in-feed treatment rather than bath treatments to reduce dispersal into environment. Alongside this has been the development of vaccines to reduce the requirements for medicinal treatments
- There have been moves towards a general reduction in the use of antifoulants and increased use of eco-friendly antifouling coatings and products.

In a wider context, regional management approaches are also important.

- Single bay management plans help coordinate fallowing and treatment of pathogens throughout a water-body to reduce overall inputs of chemo-therapeutants.
- There has been a growth in the use of wide-scale programmes for sustainable management of mariculture. One such example is ECASA (Ecosystem Approach to Sustainable Aquaculture), an EU funded project. It has significantly contributed to understanding of the effects of aquaculture on the environment both in the OSPAR region and the Mediterranean. ECASA included both fin and shell fish marine aquaculture and has actively sought stakeholder participation from the outset. ECASA is an internet based, virtual toolbox which contains 'tools' to aid site selection for fin-fish and shell-fish farm

and their operating so as to minimise environmental impact and ensure the sustainability of sites and water bodies for aquaculture

- Implementation of integrated coastal management tools may help predict the environmental impacts of mariculture activities. Models such as DEPOMOD (Cromley *et al.*, 2002) and TRIMODENA are examples of methods of predicting the environmental impact of aquaculture on benthic ecosystems. SMILE (Sustainable Mariculture In northern Irish Lough Ecosystems) was established to evaluate the sustainable carrying capacity for aquaculture in the loughs of Northern Ireland, considering interactions between cultivated species, targeting marketable cohorts, and fully integrating cultivation practices: (http://www.ecowin.org/smile/index.htm);
- Increased use of integrated mariculture practices (polyculture) or co-location of complementary culturing activities (*e.g.* seaweed and shellfish culture) can help reduce nutrient outputs of caged farms and provide an additional product.
- From a regulatory perspective, there has been more effective enforcement of regulations and establishment of permanent monitoring programmes, both to evaluate external factors affecting mariculture as well as impacts of mariculture in the environment. In addition, coordination between official institutions and farmer groups and the integration of codes of conduct and regulations has;
- training in modern more environmentally sound techniques for farmers and more effective dissemination of technological advances amongst farmers (FAO, 2007).

3.3 Feed improvements

Research continues into means for the sustainable production of fish feed without reliance on wild fish. These include the use of sustainable fisheries for feed, substituting vegetable oils for some of the fish oils in feed, the use of trash fish or fish discards from traditional fisheries and breeding cultured fish capable of converting the oils from vegetable matter into more desirable fish oils without loss in taste or quality (Read and Fernandes, 2003). In their review of the utilisation of sustainable plant products in aquafeeds, Gatlin et al. (2007) state that plant feed for aquaculture must “provide nutritious diets that will effectively grow aquatic species with minimal environmental impact and produce high-quality fish flesh to confer human health benefits in a cost effective manner”. They evaluate the nutritional content, bioactive compounds and palatability of oilseeds, legumes and cereal grains as well as strategies and techniques to develop them as sustainable replacements for fishmeal.

3.4 Vaccines for sea lice

Although the salmon sea louse is an ectoparasite, it can be affected by immune components of the host’s blood and tissues (mucus and skin) on which it feeds. This principle is being used to research a vaccine, based on the model developed for a vaccine against the terrestrial cattle tick, *Boophilus* microplus. Using a protein present in the parasite’s digestive system, the cattle develop antibodies which affect digestion and reproduction in the tick. Norwegian vaccination trials have shown a significant promise with experimental vaccines based on proteins isolated from the salmon *L.salmonis* eggs. In addition, the National Research Council of Canada in association with a Canadian vaccine manufacturer has identified and patented several potential antigens to be included in a recombinant sea louse vaccine and the efficacy of some of these antigens have been tested in laboratory trials (Boxaspen, 2006).

3.5 Offshore mariculture

Offshore mariculture is viewed as a potential means of large scale sustainable culture of fish and shellfish with minimal environmental impact. Offshore sites tend to have more stable sea temperatures, better water exchange, less pollution and potential for disease contamination than inshore sites, less user conflicts and less maintenance as the equipment is more robust so as to handle stormy ocean conditions. However, it is important that this industry, which is in its infancy, learns from the experiences of the inshore aquaculture industry and carefully considers the potential environmental impacts and means of mitigation.

Although the environmental impacts of offshore mariculture are thought to be very much diminished in comparison to inshore mariculture due to the higher water exchange and better flushing of wastes (Christensen, 2000), there are concerns about biosecurity. Questions remain over the measures to be taken to prevent fish escapes and proliferation of pathogens and invasive alien species. As it would be most efficient to operate offshore farms remotely, it is essential that monitoring systems are sensitive enough to detect damage to cages, fish escapes and mass mortality events as quickly as possible so that mitigation measures can be employed. This remote sensing would have to include a means of continuous estimation of cage biomass to monitor escape events. Contingency plans for the reduction of impact from fish escapees could include use of local stock, sterile fish and improvement in strength of cages. Offshore fish farms have the potential to become fish aggregating devices, whereby local fish populations will aggregate around the floating structures in the open sea for shelter and protection from predators. It may be necessary to form exclusion zones around the structures to prevent traditional fishing methods from overexploiting these aggregations of fish.

There is much potential for the integration of different offshore infrastructures for offshore mariculture. Fixed foundation offshore wind turbines could be employed in multi-use designs for mariculture, such as longline mussel culture, tray oyster culture and use of floating collars for seaweed culture. The costs for construction could be shared between the interested parties as can foreshore licensed port areas.

4. How does this affect the overall quality status?

In 2006 mariculture production in the OSPAR maritime area was 1.4 million tonnes representing approximately 4.4% of the world’s mariculture production. The demand for fish is increasing and indications are that mariculture production will continue to increase to meet this demand. Mariculture occurs in all the 5 OSPAR regions but the highest production tonnages are salmon from Region I and II. The impacts of mariculture on the environment are generally site-specific and localised in nature there are, however, a few important exceptions.

Impacts from shellfish activities are localised and physical in nature and occur during seed collection, relaying and the harvesting of product. These include physical damage to habitat and disturbance of birds and mammals. The introduction, accidentally or intentionally, of alien species has far field impacts and are a cause for concern. Combined with climate change the implications of these introductions are difficult to assess or predict. The establishment of naturalised populations of Pacific oysters in Regions II, III and IV is an example of the combined effects of mariculture activity and climate change resulting in conditions suitable for naturalisation of this species.

There are also a number of impacts from farming carnivorous species, such as salmon and trout that are not generally localised. These include effects on wild salmon and trout from sea lice emanating from farmed salmon cages, ecological and genetic impacts from escaped fish and a demand for feed derived from industrial fisheries of wild stocks. Adverse impacts due to nutrient enrichment by uneaten feed pellets, faeces/excreta and the effects of therapeutants are localised and more easily mitigated through the proper selection of the farm site and management practices and technology.

5. Conclusions and recommendations

Areas in need of future research are:

- the impact of farms escapees on biodiversity including the ability of wild populations to recover from the introgression of farmed genes;
- the number of broodstock required to maintain genetic diversity;

- the genetics of new target wild species as potential candidates for mariculture, including use of local species rather than alien imports;
- vaccines for infectious disease and parasites in mariculture;
- reducing the impact of collecting and using wild seed;
- the effects of chemicals and therapeutants on benthos and biodiversity, including the reduction of their use through improved husbandry practice; and
- feed improvements to reduce the requirement of fishmeal and oils derived from industrial fishing of wild stocks.

Offshore mariculture, on its own and in combination with other offshore technologies such as wind farms, has the potential for growth. Improvements in cage technology will help reduce the large number of cultured fish escapees.

OSPAR previously acknowledged that the mariculture industry is very diverse, its impacts are very site-specific, regulation and control will therefore always need to be focused on a case-by-case approach, and that a substantial amount of general guidance is available to give the background to these case-by-case decisions. On that basis, OSPAR concluded that, in the present circumstances, there is no need for the development of additional programmes and measures at the OSPAR level (OSPAR, 2006b).

This assessment reaffirms this conclusion for the time being. There are, however, a number of far field impacts identified, namely, the introduction of alien species, impacts of sea lice, ecological and genetic impacts of escaped fish and increased demand for industrial fisheries which should be periodically reviewed at an OSPAR / regional sea wide level. Information should continue to be exchanged on these issues. In addition, should mariculture activities move offshore and develop in combination with other activities; methods for assessing the cumulative impacts of such developments will be required.

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7. Glossary

Antifoulant: Substances used to coat marine netting in fish cages; some may leave unacceptable chemical residues in the farmed fish.

Autotrophy: The ability of certain organisms (most plants and a variety of bacteria and protists) to be self-sustained by producing food from inorganic compounds.

Bioaccumulation: The increase in concentration of a chemical in the tissues of organisms above that of the ambient environment. Certain chemicals such as PCBs, mercury and some pesticides can be concentrated from very low levels in the water to toxic levels in animals through this process.

Biocide: A substance or chemical agent, such as a pesticide, herbicide or fungicide that is capable of destroying living organisms.

Biodiversity: The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems.

Biosecurity: Policies and measures taken to protect from biological harm. It encompasses the prevention and mitigation from diseases, pests, and bioterrorism, of the economy, environment and public health, which includes food and water supply, agricultural resources and production and pollution management.

Bouchot: A method of culturing mussels that is primarily used along the French Atlantic coast but is applicable to other areas with a high tidal flux. Spat are collected by larval settlement on poles and ropes. Ropes with young mussels are transported to the on-growing area and wrapped around poles (*i.e.* "bouchots") embedded in the intertidal zone.

Carrying capacity: A measurement of the potential maximum production a species or population can sustain for a given time in relation to the available food in a given area, without causing deterioration or degradation of the habitat.

Cultch: Cultch is used in shellfish aquaculture as a substrate on which oyster spat can grow. The clean shell (cultch) is laid on the seabed in the area designated for shellfish growing and recognised as being likely to receive larval settlement.

Dinoflagellate: Unicellular protozoan group with two flagellae and an important component of marine plankton. Certain species are toxic and when a bloom occurs (red tide), it may cause massive mortalities of marine animals. Food poisoning in humans has also been observed.

Epifauna: Benthic fauna that live on the surface of the sediment

Fallowing: A process where sites normally used for production are left to recover for part or all of a growing season.

Fecundity: The potential reproductive capacity of an organism or population expressed in the number of eggs (or offsprings) produced during each reproductive cycle.

Furunculosis: A bacterial disease usually characterized by sores/boils or furuncles on the skin caused by *Aeromonas salmonicida.* Usually not contagious but can be spread by direct contact. Infected fish should be quarantined and treated with antibiotics.

Gadoid: Of the family Gadidae (order Gadiformes) of bony fishes including cod, hake, whiting, pollack, saithe and haddock.

Gamete: Mature sex cell (egg or sperm), haploid, that unites with another gamete of the opposite sex to form a diploid zygote; such a union is essential for true sexual reproduction.

Harrowing: A technique for reworking the sediments under cages in fish farms. In this process, the sediments are raked repeatedly with a mechanical implement, either powered by a diver or towed by a boat.

Infauna: Animals that live within the bottom sediments.

Mariculture: A specialised branch of aquaculture involving the cultivation of marine organisms for food and other products in the open ocean, an enclosed section of the ocean, or in tanks, ponds or raceways which are filled with seawater.

Mussel Mud: Accumulation layer of mussel faeces, pseudofaeces, shell debris and silt under maturing seed mussel beds. They can be 30 - 40cm thick and can detach from the underlying substratum and become unstable.

Pseudofaeces: In filter-feeders such as bivalves, material removed from the water flow, aggregated and rejected before it enters the gut.

Polychaete (bristleworm): Any annelid worm of the class Polychaeta.

Polyculture: The rearing of two or more non-competitive species in the same culture unit.

Salmonid: Belonging or pertaining to the family Salmonidae, including the salmons, trouts, chars, and whitefishes.

Seed: Eggs, spawn, larvae, fry or spat of aquatic organisms being cultured. Obtained from the wild or from captive breeding programmes.

Smolt: A young salmon at the stage intermediate between the parr and the grilse, when it becomes covered with silvery scales and first migrates from fresh water to the sea.

Spat: An oyster or similar bivalve mollusc in the larval stage.

Spatfall: Settlement of bivalve larvae on a substrate when it begins to develop a shell.

Therapeutant: A healing or curative agent or medicine.

Viral Haemorrhagic Septicaemia (VHS): A systemic infection of various salmonid and a few nonsalmonid fishes, caused by a rhabdovirus designated as the viral hemorrhagic septicemia virus. The virus infection may result in significant mortality. Fish that survive may become carriers.

Appendix I: Maps of selected mariculture locations within the OSPAR Maritime Area

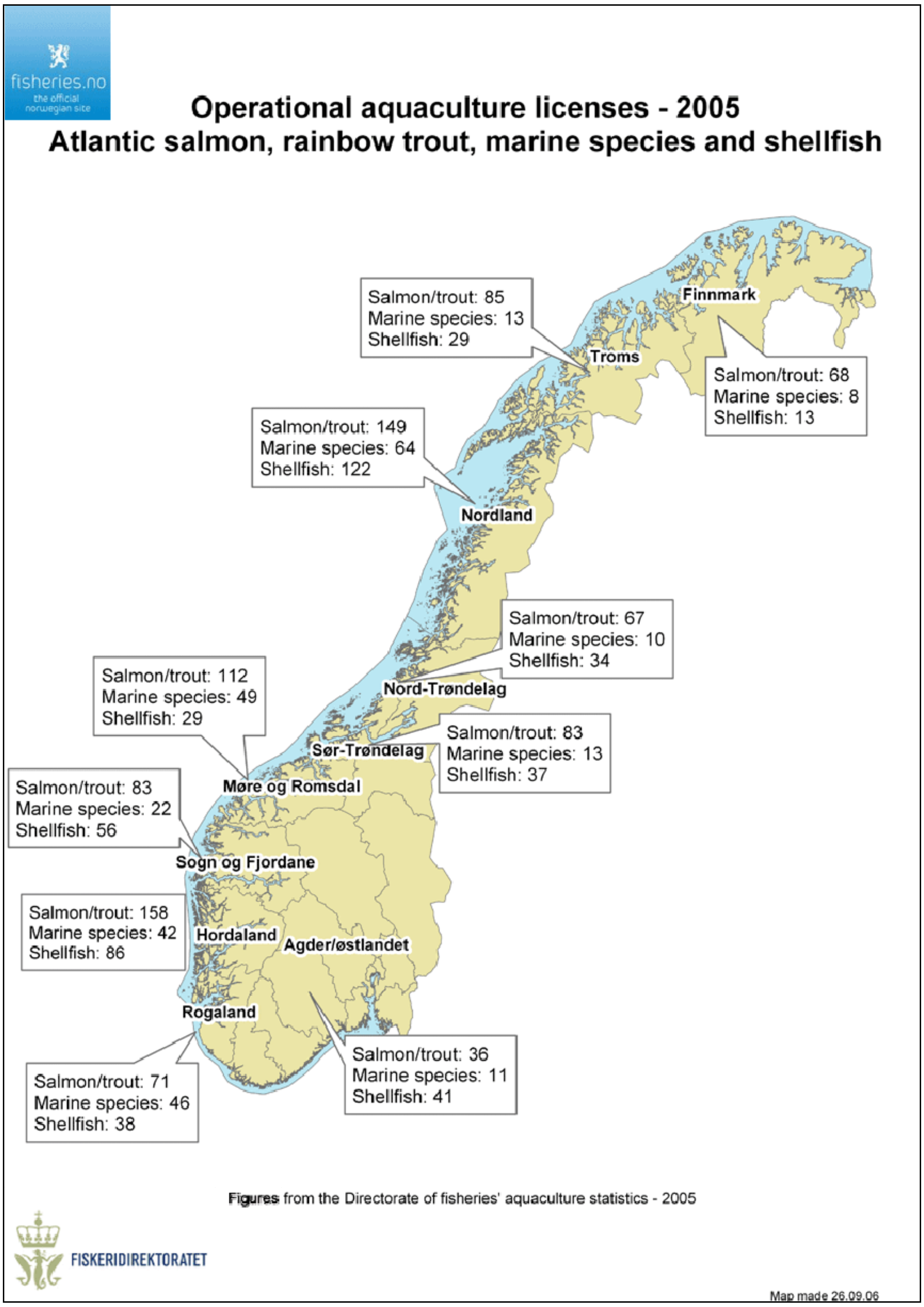

Figure A1. Norwegian mariculture locations

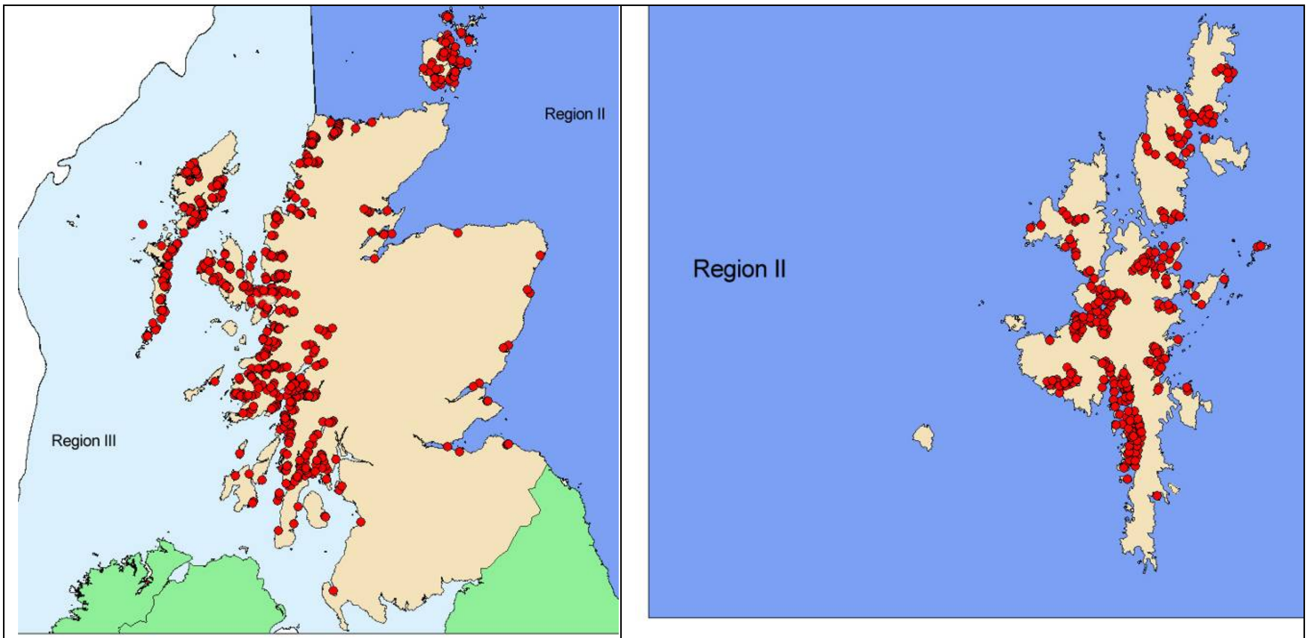

Figure A2. Scottish mariculture locations including the Shetland Islands

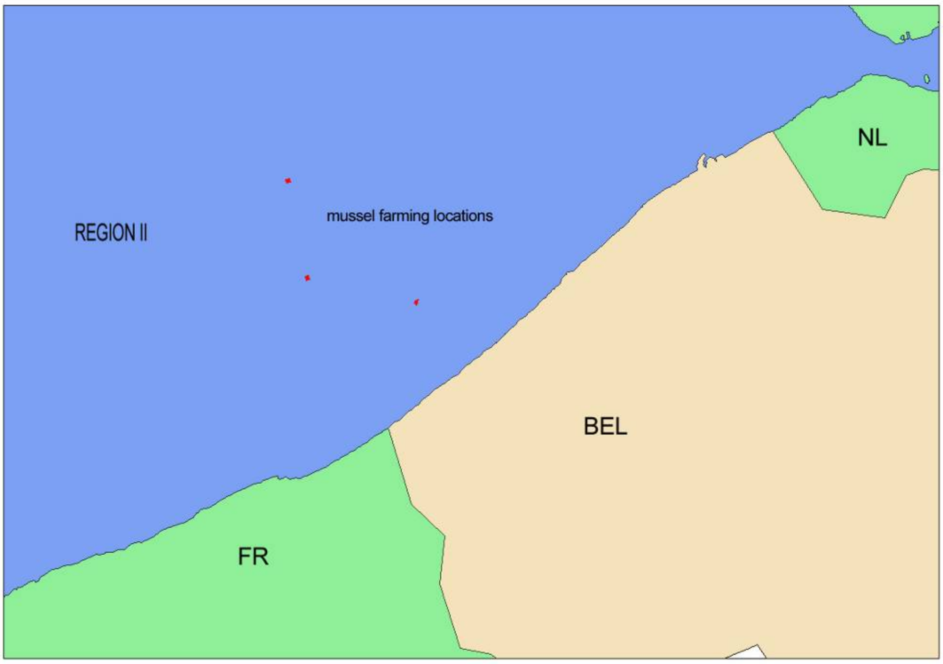

Figure A3. Belgian mussel farms

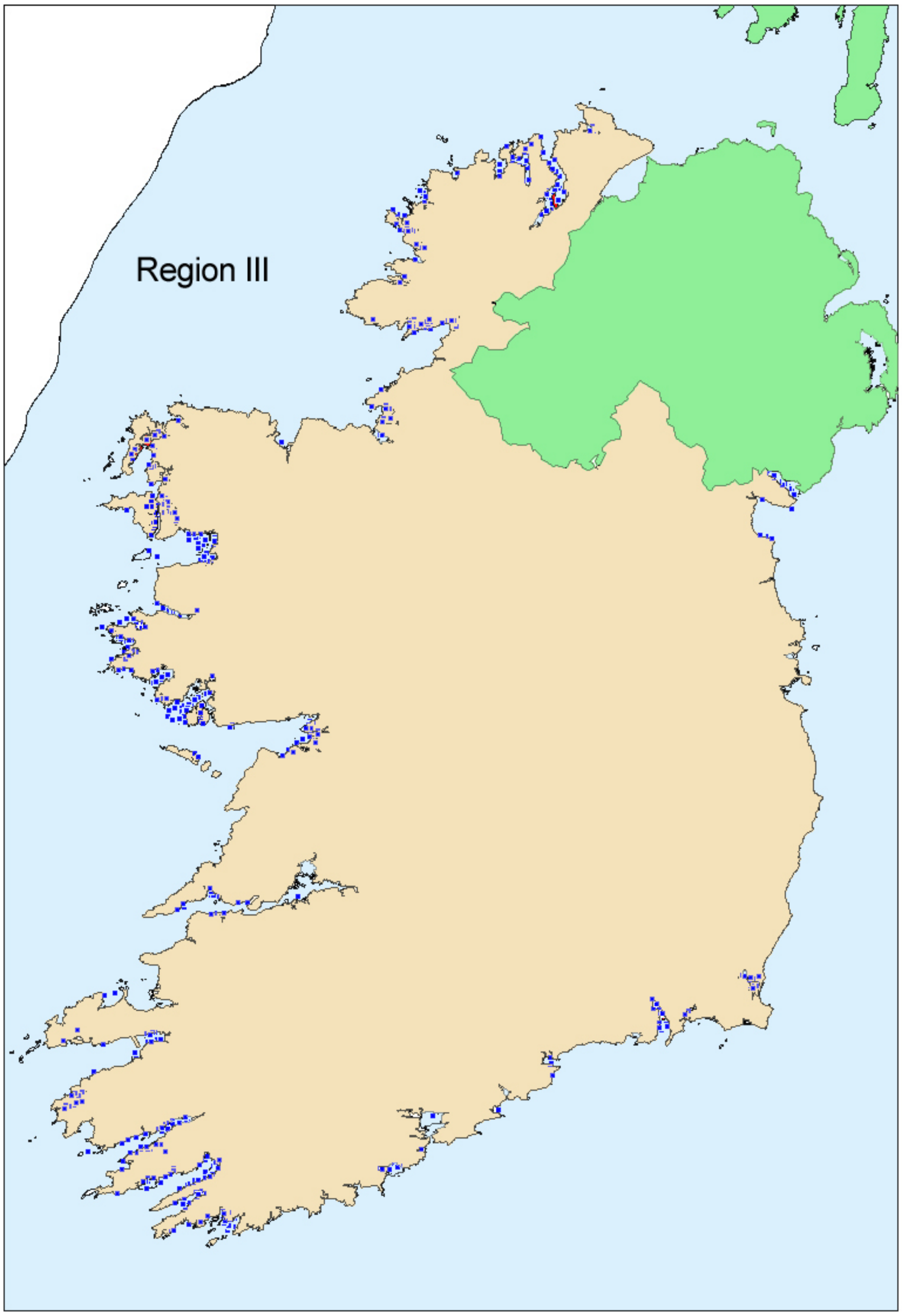

Figure A4. Irish mariculture locations

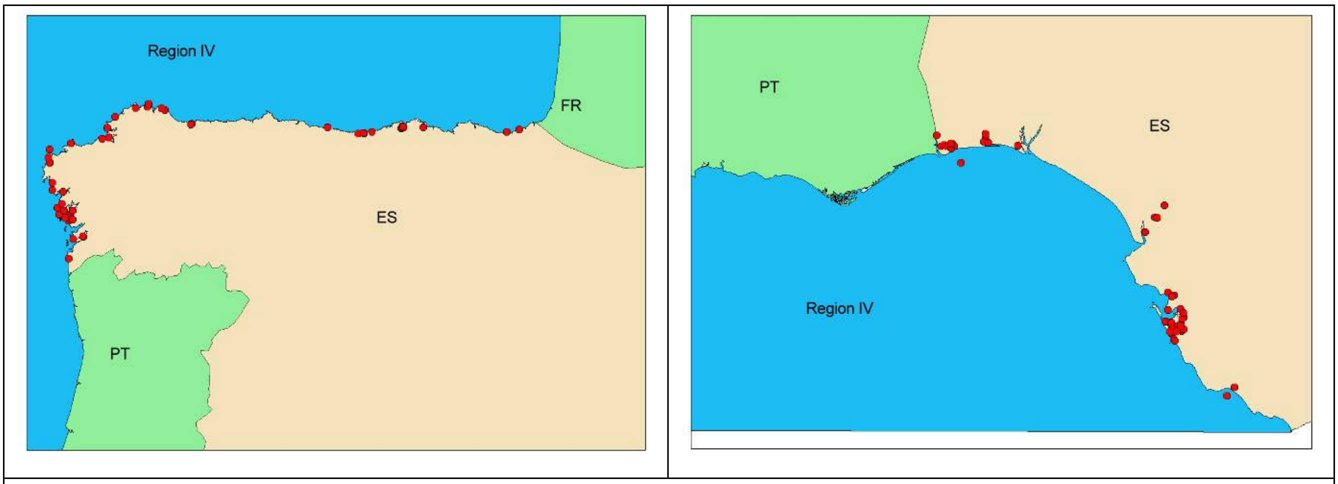

Figure A5. Location of mariculture facilities in the North West and South West of Spain.

Appendix II: Environmental toxicity information on the most commonly used chemicals in finfish aquaculture.

Active ingredient	Environmental information
Deltamethrin	Deltamethrin is highly toxic for fish, the 96-h LC_{50} ranging between 0.4 and 2.0 µg/litre and is also toxic to aquatic invertebrates (48-h LC_{50} for *Daphnia* is 5µg/litre) (WHO, 1990). The product is toxic to crustaceous animals, and it is not recommended that it be used close to installations where crabs and lobsters are kept (< 200m), or where local sea currents lead to risk of exposure (Pharmaq, 2005). However, extensive field studies, in experimental ponds, and field use have shown that this high potential toxicity is not realised. Deltamethrin is not mobile in the environment because of its strong adsorption on particles, its insolubility in water, and very low rates of application.
Teflubenzuron	Teflubenzuron is a benzoyl urea compound registered in many countries (including EC states) for use on a range of crops. Environmental data demonstrates that teflubenzuron is strongly adsorbed by soils and sediments and has a low potential for bioaccumulation. Studies with the use of teflubenzuron by the Scottish Environmental Protection Agency (SEPA) in salmon farms in Scotland confirmed that although measurable levels of teflubenzuron were noted at distances up to 1000m in line with the main current flow, by 645 days after the last treatment, around 98% of the total load had been degraded or dispersed from the treatment site. In addition, no adverse effects were detectable on benthic biology or site crustacea and it was concluded that by later stages residual teflubenzuron was in a non-bioavailable form (SEPA, 1999).
Diflubenzuron	Diflubenzuron is an acycl urea derivative for use in the treatment of sea lice infestations in atlantic salmon. Diflubenzuron is practically nontoxic to fish and aquatic invertebrates. The LC_{50} values (96-hour) for diflubenzuron in various fish are: bluegill sunfish, 660 mg/l; rainbow trout, 240 mg/l; saltwater minnow, 255 mg/l; and channel catfish, 180 mg/l. In oyster larvae and juveniles EC_{50} values were 130 and 250 mg/l, respectively. Arthropods are most susceptible in the premolting stage. For instance, fiddler crabs, exposed for as little as 1 week at levels up to 0.05 mg/l exhibited limb regeneration effects. Fish tissue can show some traces of the metabolites when water is contaminated with diflubenzuron; however, tissue concentrations decline steadily with time in clean water. (EXTOXNET - Webpage) Monthly and bimonthly application of 10 ug/l diflubenzuron were reported to reduce zooplankton abundance and species richness, causing algal biomass to increase because of decreases in invertebrate grazing. Significant declines were also observed in juvenile bluegill biomass and individual weight, probably because of decreases in invertebrate food resources (Scottish Executive Central Research Unit 2002)
Dichlorvos	Dichlorvos is an insecticide of the organophosphate (OP) group. Dichlorvos is toxic to fish and aquatic arthropods are more sensitive than fish. It is highly toxic to birds and to honey bees. A review by the Australian Pesticide and Veterinary Medicines Authority (2008) stated that reports generally indicate dichlorvos to be highly toxic (LC_{50} in the range 0.1 - 1 mg/l) to moderately toxic (LC_{50} in the range 1 to 10 mg/l) to fish, with a few reports indicating slight toxicity (LC_{50} in the range 10 - 100 mg/l). The range in acute toxicity (LC_{50}) of dichlorvos to fish from these studies was ~0.2 mg/l to >40 mg/l, with the lowest value being 0.122 mg/l for larvae of the herring. (Australian Pesticide and Veterinary Medicines Authority, 2008)

Active ingredient	Environmental information
Cypermethrin	This pyrethroid has also been widely used in terrestrial ectoparasite control, however, tolerance of sea lice to this medicine in some areas in Ireland has curtailed the use of the product, as can be seen in Table 5. Cypermethrin is very toxic for fish (96-h LC_{50}s were generally within the range of 0.4 – 2.8 µg/litre in laboratory tests) and aquatic invertebrates (LC_{50}s in the range of 0.01 - 5µg/l) (WHO, 1989). However, the presence of suspended solids decreases the toxicity of cypermethrin by at least a factor of 2, because of adsorption of cypermethrin to the solids.
Florfenicol	Both florfenicol and its metabolites enter the water column by leaching from medicated feed and faeces and by excretion in the aqueous phase of the excreta. Experimental studies of the persistence in marine sediments have indicated that the concentration of florfenicol decreased rapidly in the sediment with a calculated half-life of 4.5 days, (Hektoen *et al*., 1995). The metabolite, florfenicol amine, was detected and it appears that florfenicol is rapidly degraded in sediment.
Oxytetracycline hydrochloride	Oxytetracycline appears to have long residence times in sediments, with various half-lives reported of up to hundreds of days and trace of uptake has also been detected in oysters and crabs in close proximity to treated salmon pens in Canada (Fisheries and Oceans, Canada, 2003). Coyne *et al.* (2001) studied the fate of oxytetracyline in sediments at an Irish fish farm at Bertraghboy Bay. It was reported that concentrations in sediments declined exponentially with time and were reduced to traces after 66 days. The half-life in mussels was reported as approximately 2 days.
Oxolinic acid	Oxolinic acid is a synthetic quinolone antibiotic, used in veterinary medicine for the treatment of cattle, pigs, poultry and finfish. It is administered by the oral route, in the feed, the drinking water or as a bolus. Oxolinic acid was found to be very persistent in sediments. In the deeper layer of the sediment hardly any degradation had occurred after 180 days and a calculated half-life of more than 300 days was estimated. The residues in the top layer of the sediment disappeared more rapidly. The removal of these substances from the sediment is most probably due to leaching and redistribution rather than degradation. Samuelsen *et al.* (1994) showed that oxolinic, acid sustained its antimicrobial activity over a six-month period in sediment material. (Danish Environmental Protection Agency, 2002) Biodegradation T½ = 150 to 1000 days Superficial sediment at various sediment depths (up to 7 cm)
Flumequine	Flumequine is a synthetic antibiotic belonging to the quinolone group and is active against Gram negative bacteria and is found to be very persistent in sediments. In the deeper layer of the sediment hardly any degradation had occurred after 180 days and a calculated half-life of more than 300 days was estimated. The residues in the top layer of the sediment disappeared more rapidly. The removal of this substance from the sediment is most probably due to leaching and redistribution rather than degradation. Samuelsen *et al*., (1994) showed that flumequine sustained their antimicrobial activity over a six month period in sediment material (Danish Environmental Protection Agency, 2002). Test Organisms: Artemia salina LC50 (24 hours) = 477 mg/l LC50 (48 hours) = 308 mg/l LC50 (72 hours) = 96 mg/l Biodegradation T½ = 150 days Surface sediment

Active ingredient	Marine environmental information
Fenbendazole	This is a broad spectrum antihelminthic effective against endo- and ecto-parasites in salmon, cod and rainbow trout. It is insoluble in water and has high stability. Limited withdrawal time is needed for fish treated with this method destined for human consumption (Cawthron Institute, 2007) The British pharmacopoeia chemical reference substance – MSDS indicates that it is: Harmful to aquatic organisms and may cause long-term adverse effects in the aquatic environment, and provides the following data: LC50 (fish-96h): >500 mg/l; EC50 (daphnies-48h): 12 mg/kg; Bioaccumulation and mobility: Log Pow: 3.85. May redistribute into fat and persist. (The British Pharmacopoeia Commission, 2008)
Praziquantel	Praziquantel is an anthelmintic used in both human and veterinary medicine. It is poorly soluble in water, partially solved by new liquid form (Prazipro). Binds strongly to lipids, soils and biodegraded by microflora. (**Pfizer,** 2003). Part of avermectin family, LCD50 for Rainbow trout 0.000025 g/m^3. Studies have indicated minimal praziquantel accumulation with the body tissues of fish. Using a 24-hour dosing interval, praziquantel appears only likely to accumulate in a very limited manner in the skin or plasma of kingfish, which is believed to be due to the rapid clearance of the drug, either via hepatic metabolism or renal excretion, rather than poor absorption (Cawthron Institute, 2007).
Benzocaine	Anaesthetic used during egg and milt stripping.
Tricaine methane sulphonate	Tricaine methane sulphonate is used as a bath solution to sedate and anaesthetise fish for examination. It is used as a local anaesthetic in humans. It is used for fish at concentrations of 15 to 200 mg/l and is rapidly absorbed through the gills. The elimination half-life in salmon muscle is 70 minutes (in freshwater) and tricaine is rapidly metabolised by the liver (EMEA, 1999). The compound is assumed to be biodegradable but it is recommended not to discard it into the environment (Pharmaq, 2001). The toxicity of TRICAINE-S was measured by standard methods in laboratory bioassays with rainbow trout, brown trout, brook trout, lake trout, northern pike, channel catfish, bluegill, largemouth bass, and walleye. The 24-, 48- and 96-hour LC$_{50}$ (lethal concentration for 50 percent of the animals) values for trout ranged from 52 to 31 mg/l; for northern pike, from 56 to 48 mg/l; for catfish, from 66 to 50 mg/l, for bluegill and largemouth bass, from 61 to 39 mg/l; and for walleye, the values were 49 to 46 mg/l. (Drugs.com)
Bronopol	Bronopol (2-bromo-2-nitropropane-1,3-diol) is an antimicrobial preservative, which is used in human shampoos, cosmetics, in food-contact materials and also as a bath treatment for the control of fungal infections in farmed salmonids and eggs and for bacterial challenges in cod eggs. Ecological information indicates 96-h LC$_{50}$s for rainbow trout of 20 mg/l, 48-h EC$_{50}$ for *Daphnia* of 1.4 mg/l and 72-h EC$_{50}$ for freshwater algae (*Selenastrum capricornutum*) of 0.16 mg/l (Novartis, 2004).
Emamectin benzoate	The available data indicate that the use of emamectin benzoate to treat lice infestations in salmon should create no risk of adverse impacts on sensitive pelagic life, vertebrate or invertebrate (Schering-Plough, 2002). Whilst PEC: PNEC values for sediments in the vicinity of treated farms, derived from conservative models, indicate a risk to sensitive invertebrates, measured concentrations in sediments close to the farm indicate a much smaller localised risk.
Trimethoprim and sulphadiazine	Trimethoprim has a short environmental half-life, however, sulphadiazine is more persistent.
Sodium hydroxide	The alkali, sodium hydroxide is the active ingredient in both of these heavy duty cleaning agents which are utilised on farms to degrease and clean equipment, boats, tanks, etc. prior to disinfection. It is corrosive and irritant and the organic components

Active ingredient	Marine environmental information
	are biodegradable.
Iodine, phosphoric acid, sulphuric acid	These iodophore disinfectants are used for farm equipment, tank, boat disinfection as well a for foot dips/baths and are corrosive and may cause long term adverse effects on the aquatic environment (Antec, 2004). They are generally effective against pathogens in low concentrations but are inhibited in the presence of organic matter or hard water more than most disinfectants.
Hydrogen peroxide	Hydrogen peroxide has many industrial uses as a bleaching and oxidising agent, however, there is a renewed interest in its use versus sea lice in salmon and as a disinfectant. Where it has been used as such the dosage is usually 1500 ppm for up to 20 minutes. In the absence of a stabilising agent hydrogen peroxide rapidly decomposes to oxygen and water. Although hydrogen peroxide is toxic to some aquatic organisms including marine phytoplankton and crustacean, the rates of dilution and dissociation encountered on fish farms ensure that harmful effects on the environment are minimised (EMEA, 1996).
Pentapotassium bis (peroxymonosulphate) bis (sulphate)	Virkon Aquatic is used at 0.2 to 1% for at least 10 minutes and ecotoxicology data is available for fish and invertebrates (*Salmo salar* 96-h LC_{50} 24.6 ppm, post-larvae tiger prawns 96-h LC_{50} 10.31ppm, goldfish 48-h LC_{50} 500mg/l, *Daphnia magna* 48-h EC_{50} 6.5mg/l) Antec, no date available).

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