MERMAID

mermaidproject.eu

Seventh Framework Programme
Theme [OCEAN.2011-1]
“Innovative Multi-purpose off-shore platforms: planning, design and operation”
Grant Agreement no.: 288710
Start date of project*: 01 Jan 2012 - Duration: 48 month*

In- and offshore fish farming

Deliverable: D4.6	
Nature of the Deliverable:	Report
Due date of the Deliverable:	M40 – 30/04/2015
Actual Submission Date:	M50 – 19/02/2016
Dissemination Level:	PU
Produced by:	Øivind Bergh (IMR)
Contributors:	Øivind Bergh (IMR)
Work Package Leader Responsible:	Flemming Møhlenberg (DHI)
Reviewed by:	Flemming Møhlenberg (DHI)

Version	Date	Revised Pages	Description of Changes
1.0	Feb. 16 2016	-	1st Draft released
1.1	Feb. 19 2016		Final

Contents

List of figures

1 Summary

This report describes some major environmental effects of industrial aquaculture in the context of in- and offshore farming. Emphasis is on production of Atlantic salmon, as it is the most industrialized aquaculture in Europe. Furthermore, it focuses on disease interactions, particularly salmon lice, and on organic loading.

In the contect of offshore farming, localization of farms offshore will imply a greter area of ecological impact. However, the impact is also spread and diluted, thus per area basis the impact will be reduced. Furthermore: offshore farming provides an opportunity to establish boundaries, or “fire-gates” between different production areas, separated by large geographical distances.

2 Aquaculture in the global food supply

With global capture fishery production starting to stagnate and with the increasing world population, aquaculture represents an asset with potential to produce more fish in the future, meeting the growing demand for safe aquatic products with sufficient quality (Pauly *et al.*, 1998; FAO, 2012).

FAO Fisheries and Aquaculture Department published the Global Aquaculture Production Statistics for the year 2011, in March 2013, on fisheries and aquaculture, defining a milestone in the relationship between the two activities. Data collected from FAO shows that world aquaculture production of food fish reached 62.7 million tonnes in 2011, up by 6.2% from 59 million tonnes in 2010, passing the volume of capture fisheries. Therefore, aquaculture contributed 40.1% to the world total fish production, and almost all from seaweeds production.

The data projection in Figure 1 indicates the projection for the increase in aquaculture comparing with wild fisheries which starts to stabilize or reduce. Furthermore, this point will have been reached in September 2011, taking into account the fraction of fish used for human consumption. Part of the wild catch (25-30%) is used for other purposes, including production of feed for aquaculture. In agriculture this critical point, i.e. where farming overtook hunter-gathering, was reached around 10,000 years ago in the Neolithic Period, and the transition from the older Paleolithic to the younger Paleolithic, resulting in a major cultural change.

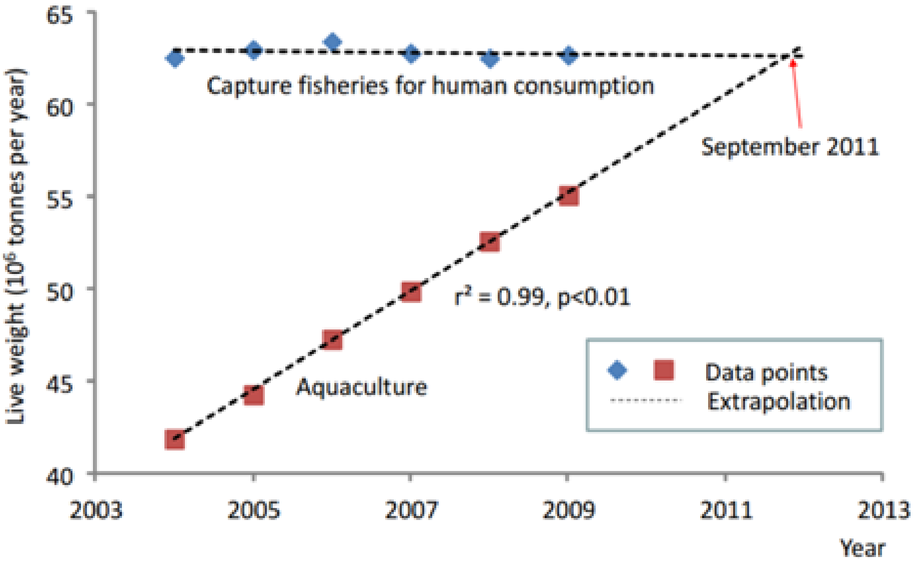

Figure 1 Fish for human consumption, divided on capture fisheries and aquaculture as sources. Figure from Joao G. Ferreira et al. (2013).

3 Salmon culture – general practices

Usually the aquaculture facilities obtain eggs from commercial suppliers; they do not hold their own bloodstock for salmon and trout. Rainbow trout are able to undertake a direct seawater transfer at approximately 50 g weight without having to be smolted beforehand and for both rainbow trout and

Atlantic salmon the production is diploid. Atlantic salmon smolts are typically light-manipulated and called S0 (ready for sea after approximately 6 months via photoperiod techniques).

All salmon smolts are injection vaccinated before transfer to sea cages. Multivalent formulations providing protection against *Moritella viscosa* (causative agent of winter ulcer disease), *Vibrio salmonicida* (coldwater vibriosis), *Vibrio anguillarum* (vibriosis), *Aeromonas salmonicida* (furunculosis) and Infectious pancreatic necrosis virus (IPN). Fish are also typically vaccinated against pancreas disease (salmonid alpha virus).

It was reported that rainbow trout are only presently vaccinated against *Vibrio anguillarum* with few if any bacterial or viral disease problems reported to date with this species in the sea cages Usually, fish are fed for a period of 16-18 months up to commercial size of 5 kg and during the growout the fish quality is checked and monitored.

The salmonid aquaculture industry has continuously restructured since 1999, with reductions in the number of farms, increased farm size and relocation of farms to deeper fjord sections (50–300 m) and current rich coastal aquaculture sites. During this transaction period, the production has doubled (Gullsestad et al. 2011), with typical salmon farm producing between 3,000 and 5,000 tons in a 18 months period in sheltered coastal waters and as much as 14,000 tons at more dynamic coastal sites. This rapid development has led to increased concerns about the environmental impacts both at present and future predicted finfish production levels.

4 Release of nutrients

Regarding the local and regional impact of organic load and release of nutrient from marine salmon farming, such environmental impact indicators and associated monitoring programmes are defined and adapted by the Norwegian fish farming authorities regarding the local zone under and close to the farms, whereas the indicators and monitoring programmes for regional effects are being implemented in some counties in Norway (reviewed by Taranger et al. 2015). The local zone under and close to the farm is monitored with a risk-based frequency using the relatively simple MOM-B method, while the more sensitive MOM-C method with detailed analysis of the species compositions in soft bottom samples near the farms is only applied occasionally. Both these methods have limitations, e.g. they require soft bottom, and are currently under revisions.

Data from regional monitoring has only become available in a few counties in the last years, but new programmes are starting up in several counties. The regional monitoring will to a large degree be based upon environmental indexes and environmental quality elements and related threshold for scoring of quality according to the Norwegian implementation of EUs Water Framework Directive.

In addition, there is a risk for release of xenobiotics, such as pharmaceutical products.

To estimate the endpoint that nutrients from fish farms results in regional eutrophication, Taranger et al. (2015) concluded that we do not have sufficient data from Norwegian coastal waters to fulfill a complete risk estimation. However, three years monitoring of nutrient values and chlorophyll *a* in the Hardangerfjord area, and in Rogaland County, a sensitive area for fish farming due to lower water exchange, show that ecological conditions for these parameters are within national acceptances thresholds suggesting high or very high water quality. Similarly, Price et al. (2015)

concluded that improvement in feed formulations and operational procedures have led to dramatic decrease in waste loss from fish farms.

Such data coupled with modelling estimations on potential increase in phytoplankton production (Skogen et al. 2009) suggest low risk of regional impacts from aquaculture in Norway. The potential increase in phytoplankton production is based on knowledge about the water transport mechanisms, coupled with typical natural values of nitrogen and phosphorous in the Norwegian Coastal Current and the calculated extra contribution to nutrient concentrations from fish farms in each Norwegian county. Assuming that theoretically all the nitrogen released from fish farms is assimilated in phytoplankton growth, an increase in the natural phytoplankton biomass were calculated and compared with the threshold of a 50% increase in phytoplankton biomass that is defined as eutrophication by OSPAR.

In terms of offshore aquaculture, the offshore farms would imply a greater area of impact, as well as a spreading of the industry to new areas previously unaffected. The acceptable impact on the water-column as well as the seabed would have to be defined.

At deep aquaculture sites, fish farming effluents can be traced into the wider environment and into benthic foodwebs up to at least 1 km from the farming site (Kutti et al. 2008). At low deposition levels, organic enrichment of benthic sediments (up to 500 m from the farming location) stimulates secondary production in soft bottom communities, resulting in shifts in benthic faunal community structure (Bannister et al. 2014). In addition, excessive loading of organic effluents to sediments often leads to dramatic changes in biogeochemical processes leading to grossly anoxic conditions. The emissions of dissolved nutrients from finfish farms are quickly diluted in the water column at dynamic sites and elevated nutrient levels are hardly detected 200 m away from the farm (H. Janssen IMR, unpublished data cited by Taranger et al. 2015).

5 Diseases in the aquatic environment

Although diseases, suffering and death have always been recognized as intrinsic parts of life as far as humans are concerned, it seems that many people tend to disregard these factors when it comes to animals. In particular, wild fish are generally assumed to be ‘healthy’, although the public concept of that term is unclear. In contrast, farmed fish are often popularly viewed as ‘unhealthy’ (Bergh 2007). Present knowledge of the importance of epizootics among wild fish is clearly limited, especially regarding viral and bacterial diseases. In contrast to the popular view, the available data indicates that disease among wild fish is common, that epizootics may be of significant ecological importance, and that there is reason to believe that fish diseases among wild as well as cultured fish may be associated with reduced welfare. The salmonid-salmon lice set of interactions may be the best studied host-parasite relationship in the marine environment, due to its significant economic and ecological impacts on the salmon farming industry and the environment in salmon-producing areas.

Large-scale aquaculture without prophylaxis is practically impossible without an unacceptable impact on the environment, reduced fish welfare, increased mortality – in turn leading to an unacceptable economy. Prophylaxis is therefore a prerequisite for modern aquaculture, as is indeed the case with salmon lice.

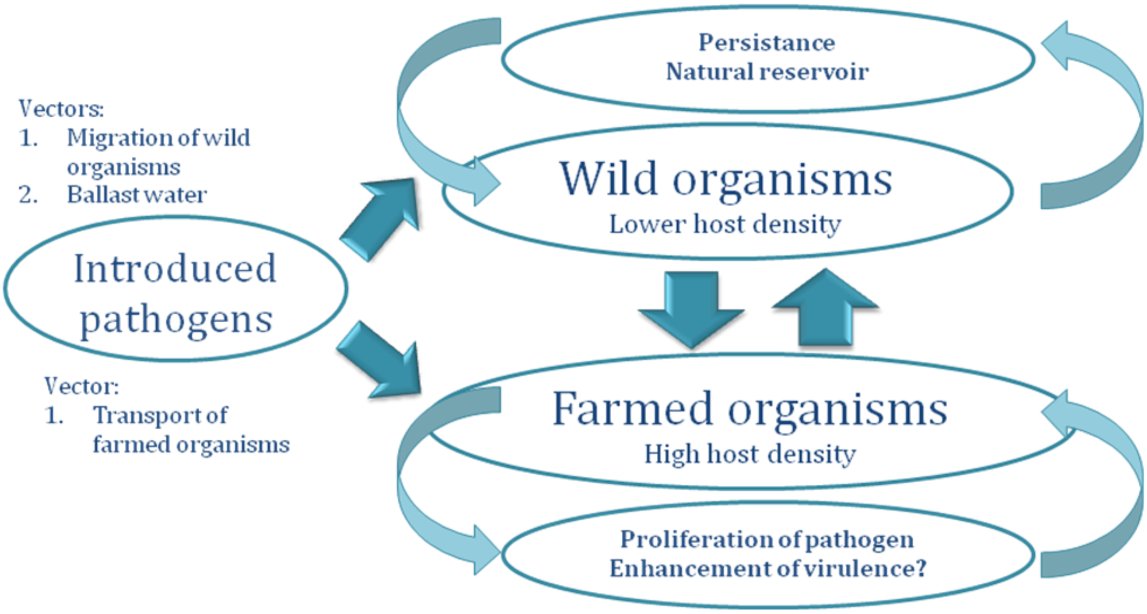

Figure 2. A general overview of the disease interactions between farmed and wild fish

Figure 2 displays general patterns of movements of pathogens between farmed and wild organisms in marine environments. Wild organisms are natural reservoirs of all known pathogens, but the reservoirs are not evenly distributed in time and space. Human influence, such as transport of farmed organisms, or movement of ballast water could move pathogens to new areas. Also, natural migration of wild organisms may cause introduction of the associated pathogens to new areas and new hosts.

Furthermore, despite the occurrence of natural epizootics they do not receive great attendance by the public. Partly, this is because infected fish may be more subject to predation, and thus are not noticed by fishermen, apart from situations where fish quality is affected (Bergh 2007). The wild situation is also characterized by a (relatively) low host density, with obvious exceptions such as schooling fish, or certain situations limited in time, including spawning.

In contrast, aquaculture by definition is characterized by high host density, acting in favor of the parasite side of the parasite-host dynamics. The open transmission of pathogens between wild and farmed hosts in cage aquaculture, which constitutes almost the entire Norwegian fish farming industry imply that the parasites and pathogens of the cultured fish are exchanged with wild fish in the surroundings.

5.1 Susceptibility of hosts

The susceptibility of any individual host to a pathogen is influenced by the complex interrelationship between the genetics of the host and pathogen, and the environment within which the host is living.

As well as being influenced by genetic variation at the host and/or pathogen level, susceptibility to disease also depends on the environment. For instance, it is well established that many diseases are more prevalent at particular times of year than others. Diseases are often temperature-dependent, with diseases that are more prevalent at higher temperatures (e.g. *Lactococcus garvieae* affecting rainbow trout, francisellosis in cod) and others that are typically only seen when temperatures drop below a certain threshold (e.g. koi herpes virus in *Cyprinus carpio* and ornamental variants and francisellosis in tilapia). Often this is the result of interplay between the ability of any particular pathogen to survive and replicate at a particular temperature range and the relative ability of the host to mount an effective immune response that is, itself, also typically temperature dependent.

Changes in physiological status, e.g. transfer of Atlantic salmon smolts from fresh to seawater can also result in increased susceptibility to diseases such as IPN. Fish that have already been exposed to disease agents may also be protected against subsequent exposure. Another obvious factor that will affect the ability of aqua-cultured animals to resist pathogens is whether they have been treated. This could include both immunoprophylaxis, where fish have been immunized by vaccination against particular diseases or chemotherapy, or if fish are treated with chemicals (including here antibiotics). For environmental reasons, antibiotic treatment is limited to a minimum in Norwegian and Scottish salmon aquaculture, whereas de-lousing agents have been frequently used against salmon lice in recent years.

5.2 Biosecurity

The application of biosecurity in aquaculture is a shared responsibility. Individuals, governmental and local authorities, and aquaculture production businesses play different roles in implementation. Biosecurity can include practical and legislative control measures, adequate diagnostic and detection methods for infectious diseases, disinfection and pathogen eradication methods, reliable high quality sources of stock, and best management practices.

Culture practice is fundamental to understand for implementing biosecurity plans to prevent disease spreading. Infections are linked to the connectivity between host and pathogens which varies with the density of the farmed animals.

The diseases of Atlantic salmon, and the disease interactions between wild and farmed salmon have been reviewed by Johansen et al. (2011). Whereas bacterial diseases such as cold-water vibriosis caused by *Vibrio salmonicida* or vibriosis, caused by *Vibrio anguillarum*, and furunculosis, caused by *Aeromonas salmonicida* subsp. *salmonicida* dominated the early years of salmon farming in Norway, the later years have been dominated by viral diseases, as well as the salmon lice.

Most diseases in Norwegian salmon and rainbow trout farms are represented by only a few outbreaks, often representing geographically separate cases. However, some diseases have a large number of outbreaks/diagnoses, and are those most likely to cause elevated infection pressures that in turn may affect wild populations. At present the most common diseases in Norwegian salmon farming are the viral diseases PD, IPN, CMS and HSMI. In addition, AGI due to *Paramoba peruans* has emerged (Norwegian Veterinary Institute 2014). Most disease outbreaks are separate events, separated in time and space. However, in the case of particularly PD and AGI in recent years, epizootics are observed, affecting areas at a regional scale.

Present biosecurity measures include the introduction of zoning, with fire-gates, separating different production areas. This is done in particular to counteract the problems with salmon lice, however it is also assumed to counteract the spreading of other epizootics.

In the context of offshore farming, the major impact would be distribution of the aquaculture activity to a larger area. It will also open the possibility to open larger fire-gates between production areas. However, the interconnectivity of the different production sites is dependent on hydrographic conditions, in particular the water currents. The optimization of localisation of farms must therefore be studied, in order to identify and establish suitable “borders” between production areas.

6 Impact on and by salmon lice by salmon farming

Salmon farming fundamentally changed the numbers of salmon lice hosts in Norway, as in Scotland, Ireland and other salmonid-farming countries. The total number of wild hosts along the Norwegian coast has been estimated at ca. 2–2.5 million fish (reviewed by Heuch et al. 2005). In comparison, the standing stock of farmed Atlantic salmon and rainbow trout was 387 million fish on December 31, 2012. In 2012, farms were stocked with 297 million salmon and rainbow trout smolts (Directorate of Fisheries, Bergen, Norway). Thus, Atlantic salmon hosts are now more than a hundred times more abundant than they were before fish farming. This has fundamentally changed the host-parasite ecology of the salmon-lice-salmon interaction.

Furthermore, the farmed hosts are also present during winter, when wild hosts are scarce in coastal waters. This breaks a natural fallowing of the habitat, promoting a higher permanent stock of salmon lice. This allows adult female lice, if they are not controlled, to continue production of larvae throughout winter. As the net pens allow the planktonic larval stages to disperse out into the surrounding waters, the infection pressure in coastal areas, where both wild and farmed salmonid smolts meet the marine environment for the first time, is increased. This development could be predicted by basic epidemiological theory as the density of hosts is positively related to the net rate of parasite infection in a population, and, furthermore, the total number of parasites that manage to establish within the host population per time increases as host density rises.

Studies of the biology of sea lice have been conducted from various perspectives for more than two decades (reviewed by Boxaspen 2006). For *Lepeophtheirus* spp., most of the published literature has centered on the economically important *Lepeophtheirus salmonis*, while for *Caligus* spp., research has focused on a wider range of species. The most numerous species of *Caligus* in North Atlantic waters, however, is *Caligus elongatus*, which is also economically important to salmon farming. Research on sea lice has developed considerably, including the application of genetic methods. Such new research has focused on life history biology, studying developmental stages under different environmental conditions (e.g. temperature and salinity), behaviour, distribution and the dispersal of free-living stages, monitoring practices, population structure, and modelling. The results of this research have informed risk analyses and allowed the refinement of management strategies to reduce sea lice infestations in wild and farmed populations of anadromous salmonids. Molecular techniques have been used to describe population structure and identify differences in genetic characterization of geographically separate populations and population markers.

Fish farmed in sea pens may become infected by parasites from wild fish and in turn become point sources for parasites. Sea lice being the most significant parasitic pathogen in salmon farming in Europe and the Americas, are estimated (Costello 2009) to cost the world industry €300 million a year and may also be pathogenic to wild fishes under natural conditions.

The current situation of salmon lice epizootics in Norway and other countries was reviewed by Johansen et al. (2012). Epizootics, characteristically dominated by juvenile (copepodite and chalimus) stages, have repeatedly occurred on juvenile wild salmonids in areas where farms have sea lice infestations, but have not been recorded elsewhere. *Caligus* species can also cause problems on farms and transfer from farms to wild fish, and this genus is cosmopolitan. Sea lice thus threaten finfish farming worldwide, but with the possible exception of *L. salmonis*, their host relationships and transmission adaptations are unknown (reviewed by Costello et al. 2009). The increasing evidence that lice from farms can be a significant cause of mortality on nearby wild fish populations provides an additional challenge to controlling lice on the farms and also raises conservation, economic and political issues about how to balance aquaculture and fisheries resource management.

The life cycle of the sea lice generally comprises five phases and 10 stages (reviewed by Johansen et al. 2012). Salmon lice have created severe problems for the aquaculture-wild salmon interaction, and this experience may serve as an example of future problems to come. After mating, the long-lived female salmon lice often move to post-anal areas of the host and may extrude up to 11 pairs of sacs with fertilised eggs for several months. Because each egg sac may contain 100-1000 eggs, a large number of planktonic offspring may be produced over the female’s lifespan. This has implications for the infection dynamics within farms and between farmed and wild host fish.

Only low numbers of salmon lice epidemics in wild salmonids have been reported before the establishment of aquaculture or in areas without fish farms (reviewed by Johansen et al. 2012). Salmon lice have typically been found at rather high prevalence but low intensity, probably in a quite regulated and stable host-parasite system, and few adverse effects on the host population have been noted. However, salmon farming has fundamentally changed the number of salmon lice hosts and also the epidemiology of the host-parasite system. In Norway, the number of salmon lice hosts have increased more than hundred times since salmon farming started, permitting adult female lice from farmed fish continuously to produce lice infestation stages into the surrounding waters. Severely increased infection intensities have been observed in intensively farmed areas. In combination with the relatively high clinical impact of salmon lice, at least at high intensities and at mobile stages, parasite induced mortality can therefore be expected. In Norway, direct parasite induced mortality in wild Atlantic salmon post-smolts, have been predicted to vary between 0 up to 95 % between years and fjords in the most intensively farmed area of western Norway. Similar mortality estimates have been predicted for sea trout in intensively farmed areas in Northern Norway, as well as for pink salmon (*Oncorhynchus gorbuscha)* in intensively farmed areas of Western Norway. Even though direct evidence of transmission from farmed to wild fish is hard to find, it is likely that salmon farming causes lice epizootics in Norway. Thus, large numbers of sea lice in fish farms pose a hazard to wild fish and control measures to reduce sea lice numbers in aquaculture are necessary.

6.1 Impact of salmon lice on survival of migrating smolts from rivers

Despite the epidemiological calculations clearly indicating that the production of salmon lice in fish farms should affect salmon, there is little evidence of a direct impact. Skilbrei and Wennevik (2006) treated cultured Atlantic salmon smolts with the anti-lice agent Slice®, orally administered emamectin benzoate, before release in the Dale River, western Norway, to study the potential effects of sea lice during the early stages of their marine phase. In total, 10,470 treated and untreated (control) fish from ten family groups were adipose fin-clipped, coded-wire tagged, and released on three different dates in 2002 (11 May, 25 May, and 7 June), which coincided with the natural smolt run. The percentage of released smolts recaptured as one-sea-winter salmon in 2003 did not differ between the treated and untreated groups released on the two dates in May 2002, but the recapture rate of fish from the treated group released on 7 June 2002 was almost twice that of the controls. The weights of the recaptured one-sea-winter salmon tended to decline from the first to the third release date, and one-sea-winter salmon from the treated groups were approximately 15%

heavier than the controls. The difference in recapture rate between the treated and untreated groups increased after inclusion of the two-sea-winter and three-sea-winter salmon recaptured in 2004 and 2005, respectively. The authors concluded that the infestation level of salmon lice changed from non-lethal to lethal levels during the period of the smolt migration in 2002 and that non-lethal infestation levels may adversely affect Atlantic salmon populations by reducing the growth rate of fish and, consequently, their size at spawning.

The conclusion is supported by studies of host density thresholds (Krkosek 2010, Krkosek et al 2012) indicating that the host density of farmed Atlantic salmon is so high that it influences the survival of wild salmon, unless treatment against salmon lice in farmed fish are carried out at an efficient level.

6.2 Efforts to reduce the impact on salmon lice and diseases on fish farming and the environment

Efforts are continuously being made to reduce the risks of pathogen transmission from aquaculture sites and there is great concern about the potential effects of diseases spreading to wild populations. Likewise, there is a risk of diseases spreading from wild to farmed fish, with subsequent proliferation and spread of pathogens in the farms as well as into the environment. However, , there is a need in both the fisheries and aquaculture industries for an overview of knowledge in this field. In the case of salmon farming, the salmon lice is of particular importance, thus significant research efforts are being carried out in order to reduce potential problems.

There are a number of recent reviews and reports covering areas of the subject – for example ”Salmon Aquaculture Dialogue Working Group Report on Sea lice” (Revie et al., 2009), ”Salmon Aquaculture Dialogue Working Group Report on Salmon Disease” (Hammell et al., 2009) and ”Review of fish disease interactions and pathogen exchange between farmed and wild finfish and shellfish in Europe” (Raynard et al., 2007), and “Disease interactions and pathogens exchange between wild and farmed fish populations with special reference to Norway (Johansen et al. 2012).

The aquaculture industry, the research community, governmental institutions as well as NGOs representing environmental protection interests, tourist and leisure fisheries are generally considered stakeholders in this work.

6.3 Models for studying dispersal of pathogens

Compartment-based models assume that individuals go through a series of states from susceptible to infected and potentially back – or to resistant. Among important information that can be derived is a maximum (susceptible) host carrying capacity for which a pathogen cannot persist, often referred to as the critical threshold NT. In aquaculture, the ratio NT/N, where N is the total population, may be manipulated by enhancing resistance through selective breeding, improved biosecurity, or immunoprophylaxis; improved management has the potential to increase the maximum density at which a species can be reared safely with respect to the risk of pathogen proliferation.

Network based models take into account the contacts between populations and individuals that actually do take place, for instance including data on movements of populations, water currents or vectors of transfer. Much useful information can be obtained merely by examining the network properties *per se,* without parameterising for a particular disease.

Hydrodynamic models have been applied to monitor spreading of pathogens in coastal and fjord environments. Such models have been applied particularly to salmon lice. By elucidating the potential of salmon lice larvae to spread over long distances, the models have provided useful input for improved management regimes and legislation, emphasizing the need for synchronous antiparasitic measures in large management zones. Whereas compartment-based models and network based models are useful for describing transfer and spreading of many viral or bacterial diseases among fish farms, they make less sense for studies of a widespread naturally occurring parasite as the salmon lice.

6.4 Modelled production of salmon lice

Heuch and Mo (2001) modelled the production of salmon lice on the part of the Norwegian coast where most farms are situated. The model focused on the period of the smolt runs (April–June) and used publicly available data on host and lice numbers. At two adult female lice per farmed fish, which was the maximum number allowed by Norwegian regulations until 2000, an estimated 111 billion lice eggs would have been produced by farmed fish in 1999. The number of eggs from lice on wild salmonids was calculated to be 2.6 billion, while lice egg production on escaped farmed fish was estimated at 15 billion. The model predicts that if the allowed limit is set lower than 0.5 adult female lice fish^{-1}, more lice eggs will be produced on escapees than on farmed salmonids. The number of salmon in farms increases with time; thus the total number of lice will increase if the number of lice per fish is fixed. For lice egg production to remain constant, the state allowable limit must therefore be lowered every year. However, the level of lice production at which wild salmonid stocks are undamaged is unknown.

Escaped salmon and rainbow trout may, however, also carry significant numbers of adult female lice. In 2012 and 2011, 38 000 and 368 000 fish escaped from farms according to official statistics (Directorate of Fisheries, Bergen, Norway).

Wild Atlantic salmon returning from the ocean naturally carry adult female lice Bag net catches show that homing salmon are also infected by substantial numbers of juvenile lice, which must have settled as the fish. This feature appears to be a function of salmon farming. If homing salmon stay in fjords and coastal areas for prolonged periods, high numbers of mature female lice may develop. In areas with large salmon rivers, wild salmon may therefore be an important local source of infective lice stages. The number of sea trout and Arctic charr (*Salvelinus alpinus* L.) is very small compared to the number of farmed salmonids (Heuch et al. 2005)

The AkvaVis is a dynamic GIS tool for siting fish farms, and a prototype version is available for mussel and salmon farms. AkvaVis combines mapable characteristics such as depth, currents and distance from other objects, and it enables objects to communicate their properties to one another in order to determine the best locations for farms. AkvaVis also calculates the carrying capacity of individual sites by means of mathematical simulation models. The prototype was developed for the Hardangerfjord, and included a survey of the topography, hydrography and currents of this fjord.

The user interface is web based. The active object (fish farm) is moved around in the area, and all other objects (other farms and points of dispersal) are related to this. The software is not designed to take decisions for the user, but does provide user support to decisions. The users are essentially any stakeholder interested in Marine Spatial Planning, including decision-makers at the municipality and county level, governmental institutions, research and industry.

The software is available at http://insitu.cmr.no/akvavis/akvavis.html

It includes a demonstration video and modules for mussel and salmon farms.

6.5 Modelled distribution of salmon lice in fjords

Numerical models have been used to produce time series of salmon lice distribution in the Norwegian fjords. Sognefjorden was studied by Asplin et al. (2004), and the model has been extended for use in several fjords, including the Case study Area of COEXIST, Hardangerfjorden (Asplin et al. 2011).

Currents and hydrography were calculated from a high resolution, three-dimensional ocean model. Inside the fjords, detailed wind forcing was necessary, and these winds were produced by a meso-scale atmospheric model. The distribution of salmon lice was calculated by a three-dimensional particle advection model including temperature dependent growth. The model results show that the variability in salmon lice distribution is huge for the Norwegian fjord areas, with spreading of lice with the currents ranging from 0 to 100 km within only a few days. There is large day-to-day and year –to year variation, however, the general pattern is that the potential for spreading is very large.

Temperature is included, as development of the salmon lice larvae through the three planktonic stages is temperature dependent. Furthermore, vertical movement of the larvae is accounted for.

The main conclusion from all studies of movement of salmon lice larvae is that

1. These organisms are well adapted to being spread along large distances in the environment where they have evolved: in typical North European coastal areas with features typical of the region:
    a. A very long coastline dominated by fjords
    b. With many rivers draining into the fjords
    c. with a brackish water layer.

2. As a consequence, treatment and management approaches against salmon lice, such as de-lousing and fallowing, has to carried out in a coordinated manner in large areas.

3. An offshore farming concept must, based on experiences form the coastline, be carried out with de-lousing of large areas.

7 References

Bannister RJ, Valdemarsen, T Hansen PK, Holmer M, Ervik A. Changes in benthic sediment conditions under an Atlantic salmon farm at a deep, well-flushed coastal site. Aquaculture Environment Interactions. 5:29-47

Bergh, Ø. 2007. The dual myths of the healthy wild fish and the unhealthy farmed fish. *Diseases of Aquatic Organisms*, 75:169-164.

Boxaspen K 2006. A review of the biology and genetics of sea lice. ICES Journal of Marine Science 63:1304-1316.

Ervik A Agnalt AL, Asplin L, Aure J, Bekkvil TC, Døskeland I, Hageberg AA, Hansen T, Karlsen Ø, Oppedal F, Strand Ø. 2008. AkvaVis – dynamisk GIS-verktøy for lokalisering av oppdrettsanlegg for nye oppdrettsarter. *Fisken og Havet* 10/2008 (In Norwegian.)

FAO (Food Agriculture Organization). 2012. *The State of World Fisheries and Aquaculture*. In: FAO Fisheries and Aquaculture Department.

Ferreira, J.G: et al. 2013. Report on assessment of aquaculture and fisheries production scale effect on the environment. The Coexist project.

Gullestad P Bjørgo S, Eithun I, Ervik A, Gudding R Hansen H Røsvik I et al. Effective and sustainable use of areas for aquaculture – land of desire (in Norwegian) Oslo; Norway: Report from an expert panel appiointed by Ministry of fisheries and coastal affairs. 198 pp.

Hammel KL, Stephen C, Bricknell I, Evensen O, Bustos P. 2009. Salmon Aquaculture Dialogue, Working Group on Salmon Diseases. Salmon aquaculture Dialogue pp. 175.

Heuch PA, Bjørn PA, Finstad B, Holst JC, Asplin L, Nilsen F. 2005. A review of the Norwegian ”national Action plan against salmon lice on salmonids. The effect on wild salmonids. *Aquaculture* 246:79-92.

Heuch PA, Mo TA 2005. A modelof salmon louse production in Norway: Effects of increasing salmon production and public management measures. Diseasesof Aquatic Organisms 45:145-152.

Johansen, L-H, Jensen I, Mikkelsen H, Bjørn P-A, Jansen P, Bergh Ø**.** 2011. Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway. *Aquaculture*, 315:167-186

Krkosek M 2010.Host density thresholds and disease control for fisheries and aquaculture. Aquacuture Environment Interactions 1: 21-32.

Krkosek M, Revie CW, Gargan PG, SKilbrei OT, Finstad B, Todd CD. 2012. Impact of parasites on salmon recruitment in the Northeast Atlantic Ocean. Proceedings of the Royal Society B **doi: 10.1098/rspb.2012.2359**

Kutti T. 2008 Regional impact of organic loading from a salmonid farm – dispersal, sedimentation rates and benthic fauna response PhD thesis.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres Jr, F., 1998. Fishing Down Marine Food Webs. *Science*. **279**. 860-863.

Price A, Black KD, Hargrave BT, Morris JA (2015) Marine cage culture and the environment: Effects on water quality and primary production (Review). Aquaculture Environment Interactions 6(2): 151-174

Revie C Dill L, Finstad B, Todd CD, 2009. Salmon Aquaculture Working Group Report on Sea Lice. Salmon Aquaculture Dialogue pp. 117.

Skilbrei O, Wennevik V 2006 Survival and growth of sea-ranched Atlantic salmon, Salmo salar L., treated against sea lice before release. ICES Journal of Marine Science 63:1317-1325.

Skogen MD, Eknes M, Asplin L, Sandvik AD. 2009. Modelling the environmental effects of fish farming n a Norwegian fjord. Aquaculture. 298:70-75.

Taranger GL, Karlsen Ø, Bannister Rj et al. 2015. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming ICES Journal of Marine Science 72(3):997-1021.