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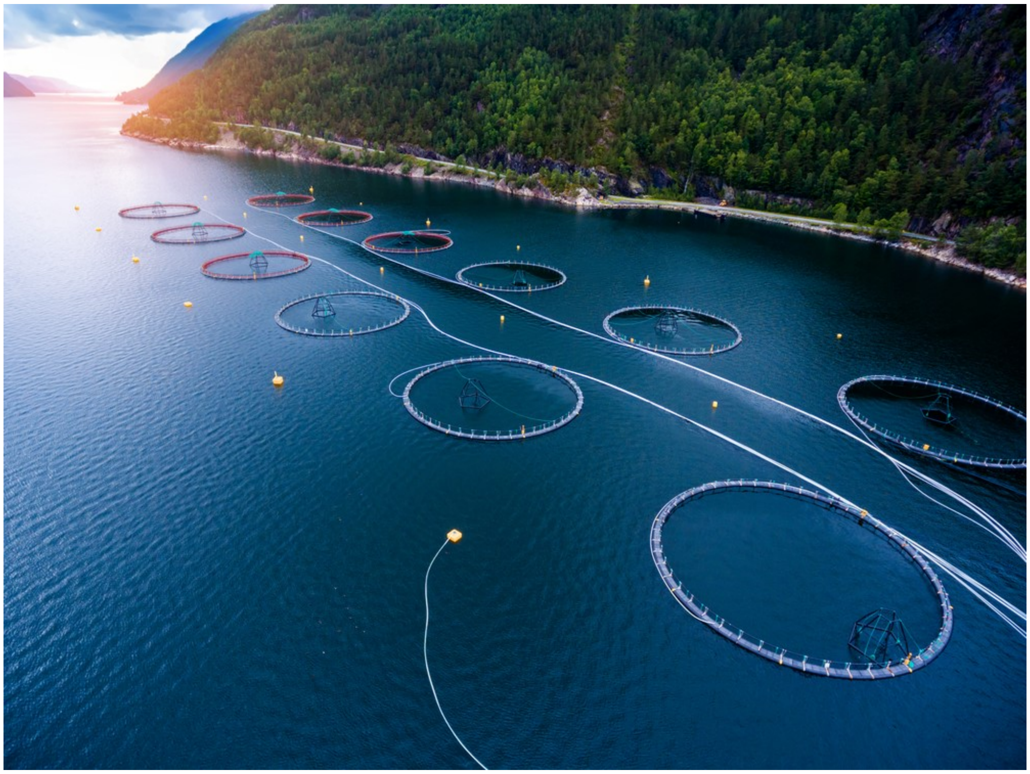

Identification and evaluation of sustainable and innovative solutions in sea lice treatment

UNIVERSITY OF STAVANGER

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Identification and evaluation of sustainable and innovative solutions in sea lice treatment

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ABSTRACT

Though 70 % of the earth's surface is covered by water, but just 2 % of all the foods come from the sea. Increase in population necessitates using sustainable solution is necessary in order to increase production and decrease mortality of fishes in farms. The fish industry in Norway is an old and specific attention is paid to fish aquaculture and fish industry. The salmon lice (*Lepeophtheirus salmonis*) infesting Atlantic salmon (*Salmo salar*) in the sea water phase is one of the major issues for the Norwegian aquaculture. To obtain health and welfare of the farmed Atlantic salmon, different innovative treatment methods are being used for controlling the sea lice. Different medicinal and non-medicinal solutions are already being applied in the farms, but a sustainable solution is still required. This thesis will identify the most recent innovative solutions in sea lice treatment in Norway and evaluate the possibility of sustainability for the solutions.

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Stavanger - May 30th, 2019

Narges Karimi

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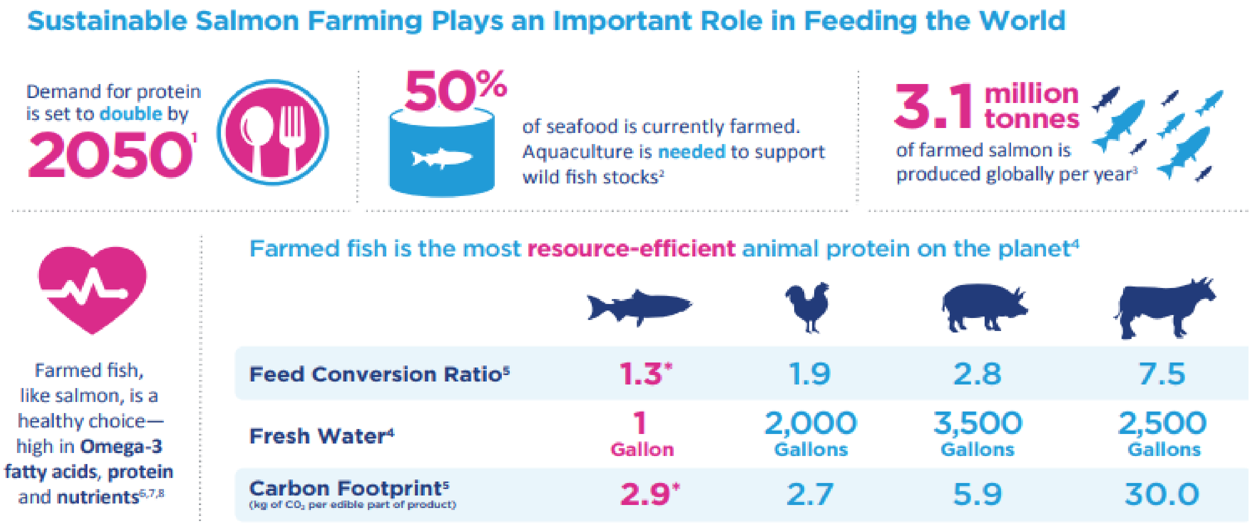
1. INTRODUCTION

1.1. Background

About 70 % of the earth's surface is covered with water, but only 2 % of all the planet's food comes from the sea (Østervold Toft, 2016). The global food system is reaching a critical inflection point. Despite massive gains in scale and efficiency over the past 60 years in agriculture, food production is surpassing the ecological limits of the planet. The process of feeding 7.6 billion people accounts for 70% of global freshwater consumption and approximately 25% of greenhouse gas (GHG) emissions, the latter primarily from agriculture and deforestation. Most of these impacts stem from growing the animal proteins demanded by a rapidly expanding population. To feed a projected population of 9.7 billion people in 2050, food production must increase by as much as 70%. A large proportion of this increase will come from animal protein demanded by an anticipated three billion new middle-class consumers. Sustainably meeting this demand will include growing more seafood with less impact on natural systems. If the global food system is to meet this challenge without imposing untenable environmental costs, the seafood sector and aquaculture in particular, will have a critical role to play (O'Shea, Scott, Markham, & Norell, 2019).

According to the report by Global Salmon Initiative, which is released in 2016, demand for protein in 2050 is set to double. Since farmed fish is the most efficient animal protein on the planet, sustainable salmon farming plays an important role in feeding the world (Figure 1)



	Fish	Chicken	Pig	Cow
Feed Conversion Ratio[5]	1.3*	1.9	2.8	7.5
Fresh Water[4]	1 Gallon	2,000 Gallons	3,500 Gallons	2,500 Gallons
Carbon Footprint[5] (kg of CO_2 per edible part of product)	2.9*	2.7	5.9	30.0

Figure 1. GSI 2016 Sustainability Report (GSI, 2016)

Within the seafood industry, Norway is a key player (Figure 2 and Figure 3), as it is home to the largest population of Atlantic salmon (*Salmo salar* L.) and the largest salmon-farming industry in the world (Heuch et al., 2005).

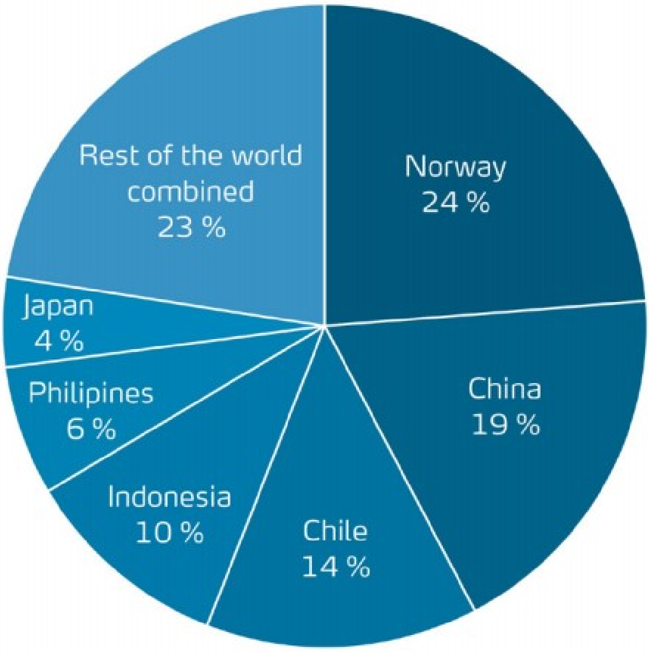


Figure 2. The world-wide share distribution of farmed fish (Christensen & Skånseng, 2016)

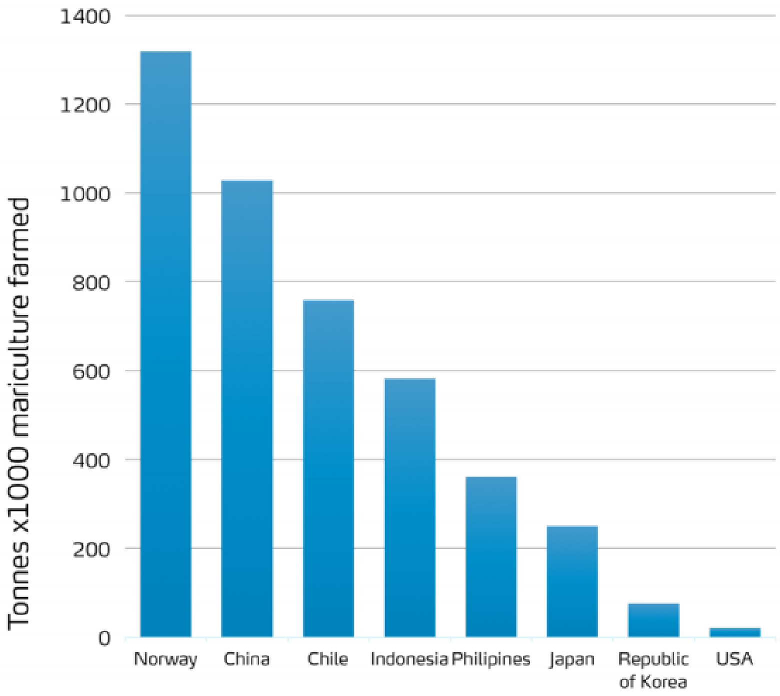


Figure 3. Top fish farming countries across the world (Christensen & Skånseng, 2016)

The seafood industry is one of Norway’s leading export industries. Each year, Norway produces about 3 million tons of seafood. Every day about 37 million meals with seafood from Norway are served around the world. The EU is Norway’s most important export market and Norway is the EU’s most important supplier of seafood (Østervold Toft, 2016). Sea lice is one of the greatest environmental challenges for salmon farming industry. Unfortunately, salmons who have been attacked by lice, *Lepeophtheirus salmonids* (*Krbyer*), emerged as a problem soon after establishment of the industry in the 1970s as is a serious threat to Atlantic salmon smolts migrating through Norwegian fjords and coastal areas in spring. However, the National Action Plan Against Salmon Lice on Salmonids was implemented from 1997 in Norway, but so far Infection with the parasite *Lepeoptheirus Salmonis* is the greatest health challenge for the fish farming industry (Heuch et al., 2005).

1.2. Theory, methodology and research design

The footprint of human activities on the Earth is called the Anthropocene. The current conceptualization of the Anthropocene refers to an emergent epoch in which humans have a documentable, substantial impact on ecosystems (Hoffman & Jennings, 2015). "*The Anthropocene presents the cycle of destruction where human habits affect other species life on the planet, which eventually comes full circle and affects mankind*" (Braidotti, 2013), and the Anthropocene Era represents an emergent awareness of a fundamental change in the intellectual, cultural, and psychological conceptions of who we are as humans and how we relate to the environment around us. The scientific community and the public are both actively looking to find a solution to reduce side effects of Anthropocene and achieve sustainability.

Institutional theory identifies environmental problems not only as technological or economic in nature, but also behavioural and cultural. It is our individual beliefs, cultural norms, and societal institutions that guide the development environmentally destructive behaviour. Under an institutional framework, challenges at the global level require new forms of institutional apparatus to coordinate. Therefore, global environmental governance must support, coordinate and regulate the introduction of novel technologies, management practices, organizational structures and institutional solutions that profoundly changes the system in which they arise (Hoffman & Jennings, 2015). In the case of sea lice, contribution of medicine treatment and increasing the ocean temperature, due to climate change, are two issues which could be considered as examples for institutional theory. Since the use of medicine in sea lice treatment is obviously done by human and climate change is most likely consequence of human activities and behaviour.

This study has implemented *exploratory* research design frame, since there has not been other research about the subject, as it has been planned to be. The data is also collected by *online research* from available and the most recent researches and companies' reports who have innovative solutions to treat the sea lice or at least reduce its level in fish industry in Norway. The study also evaluates the possibility of sustainability in the solutions and investigates if there are any sustainable innovative solution in sea lice treatment.

2. THE OCEAN UNDER CLIMATE CHANGES

Fisheries management is facing unprecedented challenges. The superimposition of climate change on overexploitation of resources is increasingly leading to unanticipated changes in marine ecosystems. Fisheries have long been concerned with the effects of the variability in weather and physical oceanographic conditions, in order to make year to year adjustments in management. In addition to local physical variables like sea temperature (e.g. Proactima Company, Figure 19), fishery biologists have recently started to use global-scale climate indices. This has been a major step towards explaining ecological patterns and processes in marine ecosystems (Le Maho & Durant, 2011). Most habitable space for life on Earth is not terrestrial. More than 90% of its liveable volume is in the deep ocean, below water depths of 200 m. The diverse ecosystems in this vast realm play a key role in regulating Earth's climate by absorbing excess heat and CO_2 from the atmosphere. The deep ocean thus helps to buffer the greenhouse effect, but in the process, it becomes warmer, more acidic, and less oxygenated (Mora et al., 2013). Such changes threaten ocean productivity, biodiversity, and provisioning of living resources. Potential loss of deep-sea biodiversity may suppress adaptation capacity and limit the living library of species, genes, and biomolecules available to future generations. The regulating capacity of the deep sea slows climate change while recycling nutrients for surface ecosystems, thus supporting food provision and providing economic and societal benefits. However, because the deep ocean is vast and expensive to access, most of its species have not yet been described. Most climate change impacts in the deep ocean will remain unknown unless attention is directed to its vulnerable ecosystems (Levin & Le Bris, 2015).

Figure 4 shows humans and climate change in the deep ocean and illustrates the depth-resolved confluence of current and proposed human exploitation activities and waste disposal with CO_2-induced change in the temperature, pH, and oxygenation of the deep ocean. (Levin & Le Bris, 2015).

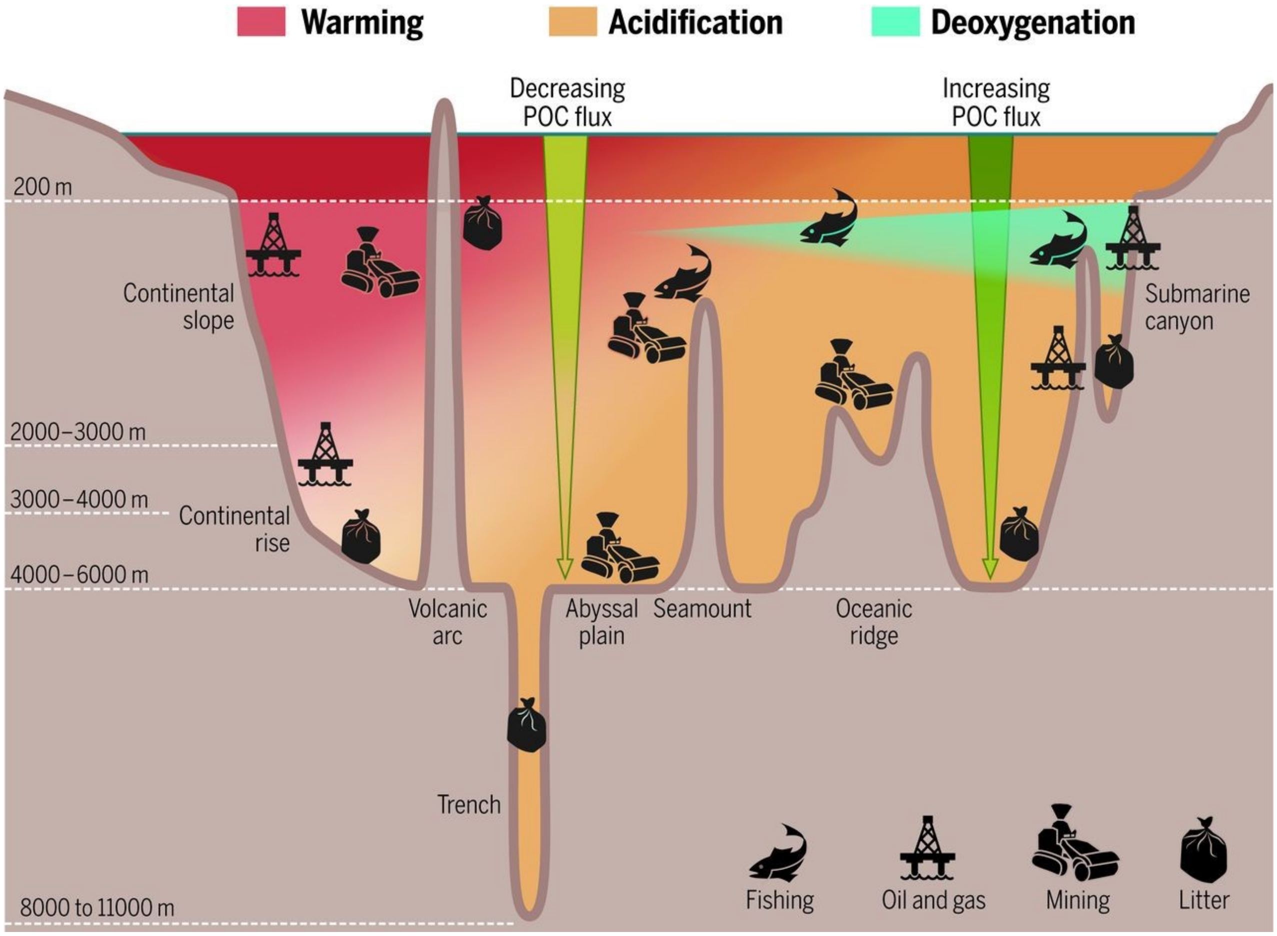


Figure 4. Relation of human activities and climate change in the deep ocean (Levin & Le Bris, 2015).

According to (Brooks & Stucchi, 2006), sea lice populations are affected by environmental conditions. For instance, warm water temperatures contributing to higher levels of sea lice. So, climate change which cause to increasing ocean temperature has direct impact on increasing the level of sea lice.

3. SOURCE OF THE SALMON SEA LICE

Fish diseases are major factors that limit the growth of the salmon industry. Sea lice (Figure 5 , Figure 6) in particular are considered to be a major threat to the farmed salmon industry in Norway (Nilsen, Nielsen, Biering, & Bergheim, 2017). Sea lice have been detected in farmed Atlantic salmon in Norway since the mid-1970s. The impact of salmon lice on wild salmon and sea trout was first reported in Norway in 1992 (Heuch et al., 2005). Despite regularly implemented chemical treatments, fish farmers still lose considerable amounts of fish due to lice (Hamza, Rich, & Wheat, 2014). The two sea lice species, *Lepeophtheirus salmonis* and *Caligus elongatus*, are copepod ectoparasites found on salmonids in seawater. They live and reproduce on fish and spread by the release of eggs into the seawater (Nilsen et al., 2017).

Figure 5. Mature female with egg strings. 2. Mature female without egg stings. 3. Immature louse (Ritchie, 2018).

Figure 6. Sea lice that have settled on fish (Canada, 2018).

The eggs hatch and develop into planktonic infective stages (Figure 7). *L. salmonis* is often referred to as the salmon lice because it is specific to salmonids, especially *Atlantic salmon* and *C. elongatus* is less host specific (Thorstad et al., 2015).

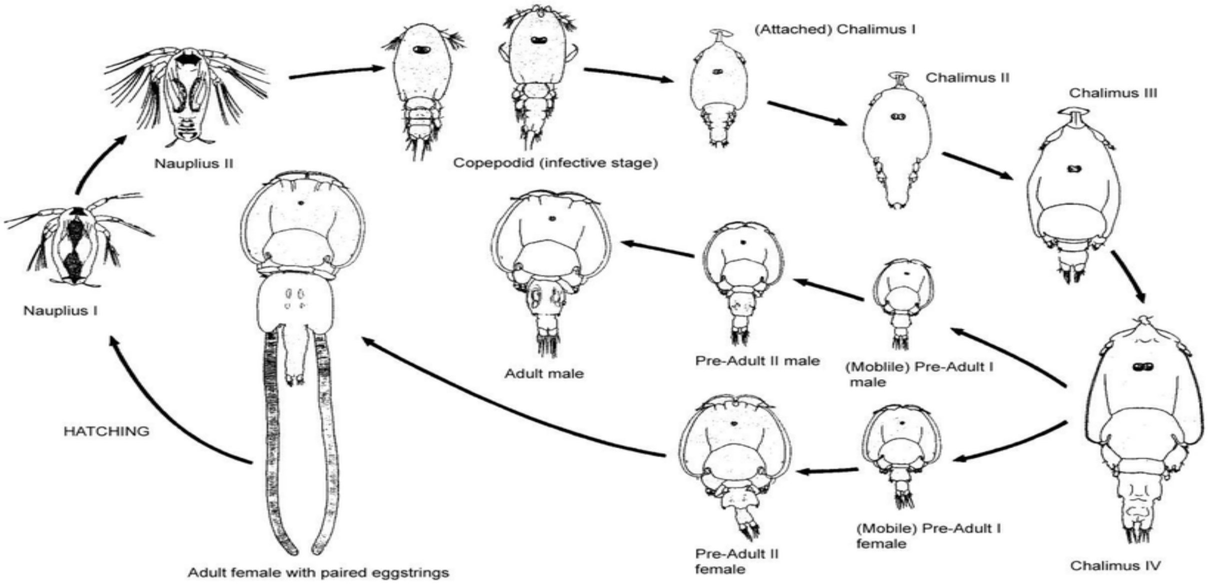


Figure 7. The stages in detail of lifecycle of the sea lice, Lepeophtheirus salmonis (Whelan, 2010).

Salmon lice is planktonic and free living in the sea during the first, post-hatching, larval life-stages, before they encounter and attach externally to the surface of the host fish. The life cycle of salmon lice comprises 5 phases, namely the nauplius, copepodid, chalimus, preadult and adult phases (Figure 8). The first phase of the life cycle is the free swimming, and non-feeding, planktonic nauplius phase. In nauplius I larvae hatch from the paired egg strings carried by the adult female and are released to the water column. Following the first moult to nauplius II, the larva then moults to the copepodid phase (comprising a single stage) in which it remains free-swimming and non-feeding. This is the infective stage when the salmon lice must find a host fish to survive. Once the copepodid has attached to a host fish, it moults to the chalimus phase. The sessile chalimus remains attached to the fish by a frontal filament and feeding is restricted to the host skin around the attachment point. This phase is followed by the immature preadult phase and finally the adult phase. The lice become mobile from the first preadult moult onwards and can move over the body surface of the host fish. Preadults and adults can swim in the water column for short periods and perhaps successfully infest other fish. Attached copepodids, chalimus, pre - adults and adults use rasping mouthparts to feed on host mucus, skin and underlying tissue including blood (Thorstad et al., 2015).

In areas with strong currents, the free swimming and infective stages may be widely dispersed from the release source (up to 100 km or more) (Asplin, Boxaspen, Sandvik, & distribution, 2011). The development rate is temperature-dependent and salmon lice can develop into the infectious copepodid stage even during the colder winter months. Salmon lice are generally absent from sites of low salinity, but various life stages of salmon lice have different salinity tolerances, and this varies with water temperature (Thorstad et al., 2015).

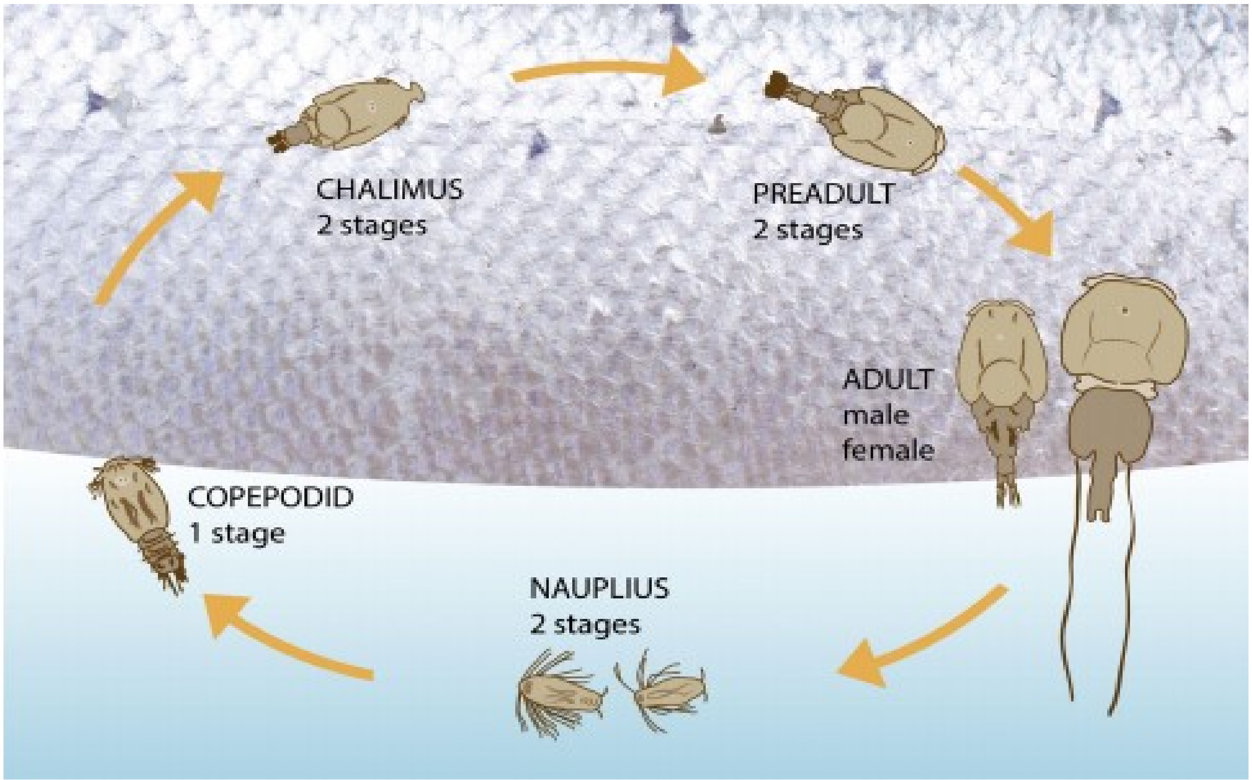


Figure 8. The 5 phases of the salmon louse life cycle (Thorstad et al., 2015).

Fish are susceptible to sea lice infestation during all stages of the susceptible production cycle (2-3 years). The appearance of sea lice related problems is unpredictable; it may happen anytime from the early stage of the sea phase life cycle of fish to slaughtering time (Heuch & Mo, 2001).

Commercial fish farming in open net cages leads to increased numbers of susceptible hosts, and thus to increased reproduction and spread of parasites. This is both a threat to the affected fish farms and to wild fish populations living in the coastal areas (Nilsen et al., 2017). The losses mostly occur as a result of delousing actions. As salmon farms provide an excellent environment to host sea lice, the areas where the farmed salmon cages are located have a much higher magnitude of sea lice infection pressure on wild salmonids (Hamza et al., 2014).

The rising number of sea lice in farmed salmon cages has increased both direct and indirect costs for fish farmers and the farmed salmon industry in Norway, in addition to the impact of sea lice on wild salmonids. These costs include increased mortality, reduced fish quality at slaughter, increased production costs per kilogram, and reduced growth performance and food conversion (Thorarinsson & Powell, 2006).

These costs reduce the profitability of fish farming. Models that assess the cost effectiveness of disease control strategies are therefore clearly of interest to the farmed Atlantic salmon industry.

The first regulation in Norway to control sea lice, the National Action Plan Against Lice on Salmonids, was enacted in 1997. The main aims of this regulation were: (1) to reduce the harmful effect of lice on farmed and wild salmon to a minimum in the long term, and (2) to monitor the number of lice per fish in the short term. Lice monitoring thresholds were implemented in 1998, they established a maximum threshold for sea lice per fish above which treatments must be applied. (Hamza et al., 2014). The reproduction of sea lice depends crucially on the number of fish present in cages and the maximum number of allowed lice per fish. As these two factors increase, the total number of lice increases (Heuch & Mo, 2001).

Researchers found that the sea temperature has a significant impact on the growth of sea lice and its population dynamics oscillatory behaviour of population dynamics of sea lice in farms is, in addition to water temperature, due to the lice growth dynamics that arise between treatment events at different stages of the farmed salmon production cycle (2–3 years). Sea lice treatment options include in-feed treatment, bath treatment, and biological treatment (Hamza et al., 2014).

3.1. The Economical aspect of sea lice treatment

Seafood is undoubtedly one of the most important food resources in the world. Any problems, like diseases, may negatively impact the food resource and result in scarcity of seafood. Diseases may cause reduction in growth, low feed efficiency and market prices, increased mortality rates, and expenditures on prevention and treatment measures. Fish farms are usually the first to suffer from diseases and may experience exacerbates negative impacts because fish farms may be disease accelerators. Strategies should thus be applied to control and minimize total disease cost, which includes biological losses and treatment costs (Figure 9). Control and prevention strategies are require minimize potential diseases and losses and increase productivity and profitability. Among various diseases associated with salmon aquaculture, sea lice have become one of the main challenges in the major farmed salmon-producing countries, especially in Norway and Canada. The treatments are costly and depend on treatment types and timing of the treatment conducted. It has been proven that treatment at an early growth stage is more economical than at a later stage. The global economic costs of sea lice to the salmon farming industry are estimated to be around US$ 423 million. For instance, the cost of sea lice was estimated to be about 0.79 NOK per kg of salmon produced in Norway in 2011 as a result of direct losses due to mortality and slow growth, treatment costs and extra manpower. If this estimate was applied to all the producers in Norway, sea lice could have cost the whole Norwegian salmon industry approximately US$130 million (1,100,000,000 NOK in 2019) (Liu & Bjelland, 2014).

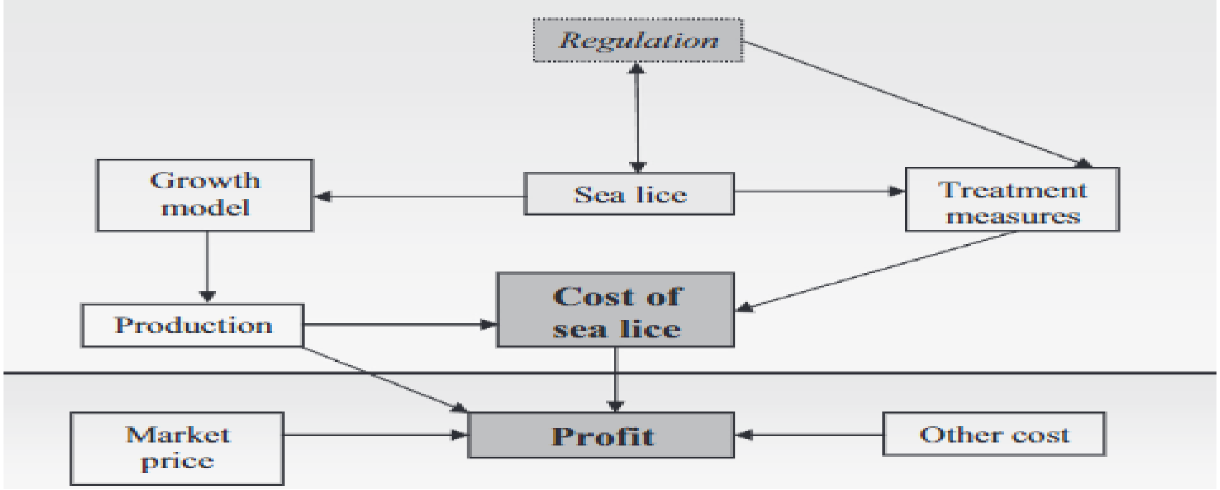


Figure 9. Schematic diagram of the sea lice cost analysis framework (Liu & Bjelland, 2014).

4. FISH FARMING IN NORWAY

The Norwegian aquaculture industry has experienced rapid growth since it entered the commercial aquaculture scene in the 1970s. In a span of just thirty years, Norway went on to contribute over 65% of the world's total production of Atlantic salmon. Today, fish farming is prolific along most of Norway's coastline, resulting in more than 1.2 million tons of salmon produced per year, with 95% of the production being exported. In terms of animal lives, approximately 780 million salmon were kept by the industry in 2015, making salmon the number one farmed animal in Norway (Dyrevernalliansen, 2016).

According to Dyrevernalliansen (2016), typical Norwegian salmon farming locality may use six to ten circular sea cages. Each sea cage can hold up to 200,000 salmon in a net that is 20 to 50 m deep and 50 m wide. The maximum stocking density is 25 kg/m^3 (10 kg/m^3 if organic), which means that each conventionally produced salmon is hosted in approximately one bathtub of water. The larger sites can hold more than 2 million salmon per generation. While disease alone can cause suffering and even mortality, stressful or harmful handling of fish such as chemical treatments for lice using hydrogen peroxide has been known to cause mass mortality in diseased fish (Dyrevernalliansen, 2016).

Atlantic salmon can be heavily infected with lice. in some fjords, such as the Alta fjord, extensive salmon farming activity can coexist with salmon fisheries, whereas in other areas, mortality of running salmon smolts due to salmon lice is estimated to be 95%. (Heuch et al., 2005). Consequently, the industry is receiving increasing pressure from environmentalists to reduce parasitic burden for wild salmon. In order to decrease reliance on, and use of, chemical lice treatments, the aquaculture industry increasingly relies on cleaner fish to control salmon lice. Cleaner fish are hailed as an environmentally friendly approach to delousing and are used as part of a parasite control approach at half of all Norwegian localities. While some have raised concerns regarding the startingly high mortality of cleaner fish, at almost 100%, cleaner fish welfare remains very poor, and they continue to be used as a disposable tool in salmon production (Dyrevernalliansen, 2016).

According to the 2017 annual report by global organization, EY (Ernst & Young), about Norwegian aquaculture analysis, there was a 5% decrease in harvest quantity of Atlantic salmon from 2015 to 2016. Despite favourable temperatures for the fish, the potential for increased harvest was hampered by sea lice challenges. Furthermore, there has been a reported increase of salmon dying in farmed cages of 16% from 2015 to 2016, which is equivalent to 53 million salmon. The main culprit for this increase in salmon death was sea lice, which is costing the industry NOK 10 billion every year (Ernst&Young, 2017). Any innovative solution which can potentially decrease the death mortality rate of salmon related to the presence of salmon lice is important to the fish farming industry.

4.1. Environmental regulation and additional pressure

Regulatory lice management systems adopted in other each country may not be successful in the other one, as the farms and their environment are different, and there is different legislation as to the use of medicines for fish. For example, in Norway researchers suggest that in some fjords, such as the Alta fjord, extensive salmon farming activity can coexist with salmon fisheries, whereas in other areas, mortality of running salmon smolts due to salmon lice has been estimated to up to

95%. Salmon farms in neighbouring areas may experience very different lice infection pressures. This means that locating the farm in the right place is an important preventive measure (Heuch et al., 2005).

5. UN SUSTAINABLE DEVELOPMENT GOALS

Figure 10. UN sustainable development goals (UN, 2015).

Oceans cover three quarters of the Earth's surface, contain 97 % of the Earth's water, and represent 99 %t of the living space on the planet by volume. Over three billion people depend on marine and coastal biodiversity for their livelihoods. Globally, the market value of marine and coastal resources and industries is estimated at $3 trillion per year or about 5 % of global Gross Domestic Product. Oceans contain nearly 200,000 identified species, but actual numbers may lie in the millions. Oceans absorb about 30 % of carbon dioxide produced by humans, buffering the impacts of global warming. Oceans serve as the world's largest source of protein, with more than 3 billion people depending on the oceans as their primary source of protein. Marine fisheries directly or indirectly employ over 200 million people. Subsidies for fishing are contributing to the rapid depletion of many fish species and are preventing efforts to save and restore global fisheries and related jobs, causing ocean fisheries to generate US$50 billion less per year than they could. Open ocean sites show current levels of acidity have increased by 26 % since the start of the Industrial Revolution. Coastal waters are deteriorating due to pollution and eutrophication. Without concerted efforts, coastal eutrophication is expected to increase in 20 % of large marine ecosystems by 2050. The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all (Figure 10). They address the global challenges we are facing, including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. The Goals interconnect and in order to leave no one behind, it is important that we achieve each Goal and target by 2030 (UN, 2015).

The world's oceans - their temperature, chemistry, currents and life, drive global systems that make the Earth habitable for humankind. Our rainwater, drinking water, weather, climate, coastlines, much of our food, and even the oxygen in the air we breathe, are all ultimately provided and regulated by the sea. Throughout history, oceans and seas have been vital conduits for trade and transportation. Careful management of this essential global resource is a key feature of a stainable future. However, at the current time, there is a continuous deterioration of coastal waters owing to pollution and ocean acidification is having an adversarial effect on the functioning of ecosystems and biodiversity. This is also negatively impacting small scale fisheries. Marine protected areas need to be effectively managed and well-resourced and regulations need to be put in place to reduce overfishing, marine pollution and ocean acidification (UN, 2015).

The 14th goal of UN sustainable development have some targets:

- By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.
- By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.
- Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels.
- Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.
- Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, (UN, 2015).

5.1. Sustainability of aquaculture in Norway

The concept of sustainable development was defined by the Brundtland Commission, formerly known as the World Commission on Environment and Development, as ‘‘the development that meets the needs of the present without compromising the ability of future generations to meet their own needs’’.

The world population is growing and putting pressure on our natural resources. This is one of the challenges to sustainable development. The aquaculture industry has the potential of contributing significantly to increasing the supply of seafood in the years ahead. The Norwegian aquaculture industry has developed from being a supplementary enterprise to a full-fledged industry, since its breakthrough around 1970. At present, Norway is the world’s leading exporter of salmon and trout, with almost 50% of the world’s total salmon production. In recent years, the export of Norwegian maricultural has increased 3-7% per year and is expected to continue to grow slowly in the future. New technologies are continuously being developed, and various species, such as Atlantic cod and Atlantic halibut, are used as farmed species. Important barriers to increased growth in the industry are the losses due to diseases and parasites as well as access to enough economical feed ingredients, especially of marine fat and protein (Olesen, Myhr, & Rosendal, 2011)

5.2. The Norwegian aquaculture in 2030

Norway endorses the UN Sustainable Development Goals and The Norwegian Seafood Federation's sustainability goals for the aquaculture industry are based on these goals. The UN has developed 17 goals and 169 sub-goals to provide global direction for countries, the business community and civil society. In the Ocean Economy in 2030, the Food and Agriculture Organization of the United Nations (FAO) and the Organization for Economic Co-operation and

Development (OECD) explain the significance of aquaculture for resolving many of future global challenges.

The Norwegian Seafood Federation aims to contribute to the UN achieving the following sustainability goals related to environmental sustainability:

Figure 11. UN sustainability goals related to environmental sustainability (UN, 2015).

- Sustainability goal 12: Ensure sustainable consumption and production patterns.
- Sustainability goal 13: Take urgent action to combat climate change and its impacts.
- Sustainability goal 14: Conserve and sustainably use the oceans, seas and marine resources.
- Sustainability goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss.

The Norwegian Seafood Federation's contribution to the UN Sustainable Development Goals is concretised in the following main objective for the Norwegian aquaculture industry.

1. The aquaculture industry will not have a negative impact on biodiversity.

   The aquaculture industry will contribute to maintaining Norwegian salmon populations. Monitoring of salmon lice and fish escape is a prerequisite for responsible operations (goals 14 and 15).

2. The aquaculture industry is to be part of the solution to climate challenges.
3. The aquaculture industry is to use the ocean in a manner that promotes environmentally sustainable development (SjømatNorge, 2014).

All food production affects the environment to some degree. In the discussion on what a predictable and environmentally sustainable growth actually entails, it is important to consider this within a perspective that also includes the major global challenges and takes into account the positive social consequences on the national level of the further development of the Norwegian aquaculture industry. The Norwegian Seafood Federation aims to ensure that aquaculture production fulfils the UN Sustainable Development Goals through local and international measures (SjømatNorge, 2014).

5.3. Sustainability in salmon production

The sustainable level for an aquaculture location or area is defined as being the maximum quantity of farmed organisms that can be produced without the environmental impacts exceeding overall tolerance levels. The tolerance levels must be measurable, and they cannot be exceeded if the aquaculture industry is to remain sustainable. The sustainability of the Norwegian aquaculture industry between Rogaland and Tromsø is being challenged by infection pressure of sea lice on wild salmonids and the possible genetic impact of escaped salmon (Hoddevik Sunnset, 2011).

In February 2019, almost 80,000 tons of Salmon were exported with a value of NOK 5.1 billion. This is an increase in volume of 7 % and a value increase of NOK 492 million or 11 % compared to February 2018. So far in 2019, 166,000 tons of salmon have been exported with a value of NOK 10.7 billion. This is an increase in volume of 4 % while the value has increased by NOK 1.1 billion or 11 %. The average price for fresh whole salmon in February was NOK 58.94 per kg, while in February 2018 it was NOK 58.34 per kg (Pettersen, 2019).

6. CONCEPT OF INNOVATION

Before studying about the innovations in sea lice treatment in Norway, understanding the relevant, fundamental concepts about innovation is important. While innovation in aquatic life, specifically in sea lice treatment, may not be perceived as a global matter, the consequence of the descending number of seafood would impact the global food industry.

Countries that produce and export salmon are currently investing in technologies and innovation in cutting-edge, low-cost treatments for sea lice. The geographical configuration of economic actors, such as firms, workers associations, organizations and government agencies are fundamentally important in shaping the innovation capabilities of firms and industries. Global knowledge networks and flows are important sources of innovative ideas for a growing number of economic activities. Firm-clustered locals require access to non-local sources of knowledge as an essential complement to the knowledge they generate and share locally. The metaphor adopted to capture the dual nature of emerging geographies of innovation is "local buzz" and "global pipeline" (Fagerberg et al., 2005).

6.1. Local buzz and global pipeline in innovation

Local buzz alludes to the collaboration of firms in the same geographical region. They are said to contribute to technological spillovers and value creation. Local buzz and global pipelines refer to structural holes and network closures, bridging and bonding social capital, and small-world networks. Local buzz can be favourable because an embedded context of local bonding can induce trust, reduce transaction costs, create knowledge spillovers, and provide fine-grained information sharing to enable the mingling of different ideas. Global pipelines play the role of bridging structures that provide access to novel and non-redundant information that can create further technological spillover and innovation. Coupled with local buzz, the two intricately-linked phenomena give rise to advantages only accessible to firms in specific clusters (Aarstad, Kvitastein, & Jakobsen, 2016).

The empirical support for the local buzz and global pipelines proposition suggests a multiplicative effect, where local buzz induces value creation if combined with global pipelines, and *vice versa*. According to Aarstad et al. (2016), both regional and international innovation collaboration can foster innovation. However, for medium-sized enterprises, typically about 50 employees strong, research only found a substitution effect from combining regional and international collaboration (compared to having either regional or international collaboration). For enterprises with less than 50 employees, there was in fact a subtractive effect. Thus, the innovation effect from combining regional and international collaboration was lower than having either regional or international collaboration. For enterprises with 50 to 200 employees, there is an additive effect, and for enterprises with more than about 200 employees, a multiplicative effect. Generally, it can be concluded that the proposed local buzz and global pipelines effect does not hold true for small and medium-sized enterprises, because of the subtractive and substitution effect. In contrast, the hypothesis gains partial to full support for large and very large enterprises, because of the additive and multiplicative effect. Also, international collaboration has an overall stronger innovation effect than regional collaboration. This may imply that global pipelines matter more for enterprise innovation than local buzz (Aarstad et al., 2016).

6.2. Regional filters

Some studies suggest that factors shaping the innovative performance of firms, such as evolutionary economics, especially in the context of economic geography, should take regional context into account as it is a fundamental aspect that affects innovation capabilities. Context and geography also generate the conditions, networks, and policy opportunities that potentially influence a firm's capacity to innovate. This includes local norms and habits, competence of local government and other institutions, as well as the amount of attention given to specific policies. In addition, how these policies shape the behaviour of firms might contribute to the emergence or eradication of moral hazards, impacted information and even insider or outsider performance that potentially condition a firm's performance (Fitjar & Rodríguez-Pose, 2015).

According to Srholec (2010), while a firm's characteristics are important for innovation, geography plays a fundamental role too. While there is no denying that the size, age, and ownership of firms influence a firm's odds to innovate, there are powerful advantages that a firm can benefit from just by being located in a region conducive to localized learning. Crucially, small firms seem to benefit more from a location in a strong innovation system as compared to large firms. In addition, young firms suffer more from adverse social characteristics of the region compared to their older counterparts. Last, but not least, policymakers should understand and adopt a multilevel perspective if they wish to be successful at promoting innovativeness of firms (Srholec, 2010).

An example of regional filter in aquaculture in Norway is reflected in the case of Tromsø. In November 2018, Tromsø politicians decided that they would not allow new farming licenses in the municipality unless the operations took place in closed facilities. It was a decision which was made by municipality, and the proposal was supported mainly by Miljøpartiet De Grønne (MDG Miljøpartiet De Grønne), Labor party, SV (Sosialistisk Venstreparti) and Rødt (Far-left political party). Although the decision was met with shock and disbelief by the industry, Naturvernforbundet (Norwegian society for the Conservation of Nature) believes that this is a step in the right direction for the fisheries policy in Tromsø (Kristine Malmo, 2018).

7. INNOVATION IN THE SEA LICE TREATMENT

Because salmon farms in different areas may experience very different lice infection pressures, the location of salmon farms is an important preventive measure and should be chosen with much consideration and prior research. Ideally, salmon lice control should be based on sustainable local and regional tolerance thresholds. The complex relationship between parasites, hosts, and the environment requires the integration of environmental and biological data for all host fish groups in the system to be established (Heuch et al., 2005). Every year, several studies are implemented to find a solution to remove or at least reduce sea lice. They must consider two main factors- environmental issues and economic issues. In the last two years, several startup companies in Norway have begun experimenting and innovating their current solution to combat sea lice. One of them is Fishency Innovation, a company based in Stavanger (Fishency, 2018).

7.1. Fishency

Fishency Innovation has developed the Smart Funnel, a system to automate sea lice counting, thus removing the need for a manual approach and its associated challenges. By focusing on monitoring and prevention rather than treatment, they have effectively created a long-term solution to combat the sea lice problem. The Smart Funnel is a specially designed, patented piece of hardware which contains a camera system and other secret technologies. By installing a Smart Funnel into the cages (Figure 12), farmers can take 360-degree photos of their fish as they swim through the funnel. These images are stored, transferred and processed using bespoke software which identifies the sea lice. The result is an automated report sent to the fish farmers via email, which gives them easy access to accurate data (Fishency, 2018).

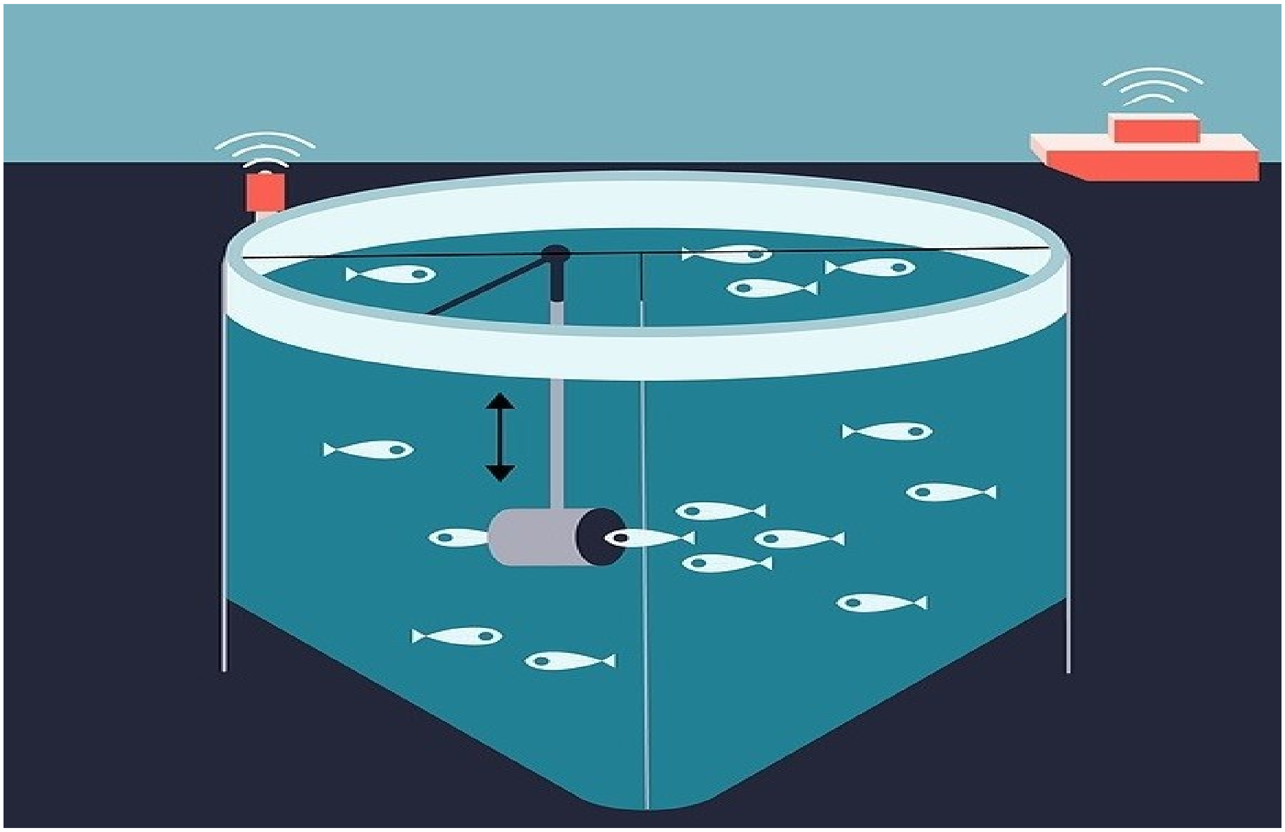


Figure 12. Model of Fishency (Fishency, 2018).

7.2. “Snorkel” sea cage technology

The other innovative solution which has been experimented by researchers is the “Snorkel” sea-cage (Figure 13). The study was conducted in Autumn 2013 at the Institute of Marine Research aquaculture station in Austevoll, western Norway (Lars Helge Stien et al., 2016). The sea-cage facility at the station has 12 × 12 m steel cages in two rows across the tidal current directions (East–West, and West–East). The experiment used three snorkel sea-cages and three control sea cages evenly dispersed across the two rows. The snorkel sea-cages had a net roof at 4 m depth, with a tarpaulin enclosed snorkel rising from the centre of the roof to the surface. Throughout the experimental period, the fish were fed in excess via a hose that distributed the feed at the surface of the cage centre, and in the case of the snorkel cages, at the surface within the snorkel. The studies concluded that there was a substantial reduction in lice infestation and little to no adverse effects on fish growth and fish welfare in the snorkel sea-cages compared to control sea-cages. Shifting from research to industrial use will mean solving numerous practical and technological challenges, in congruence with experiments that explore whether salmon can cope in such commercial-sized systems (Lars Helge Stien et al., 2016).

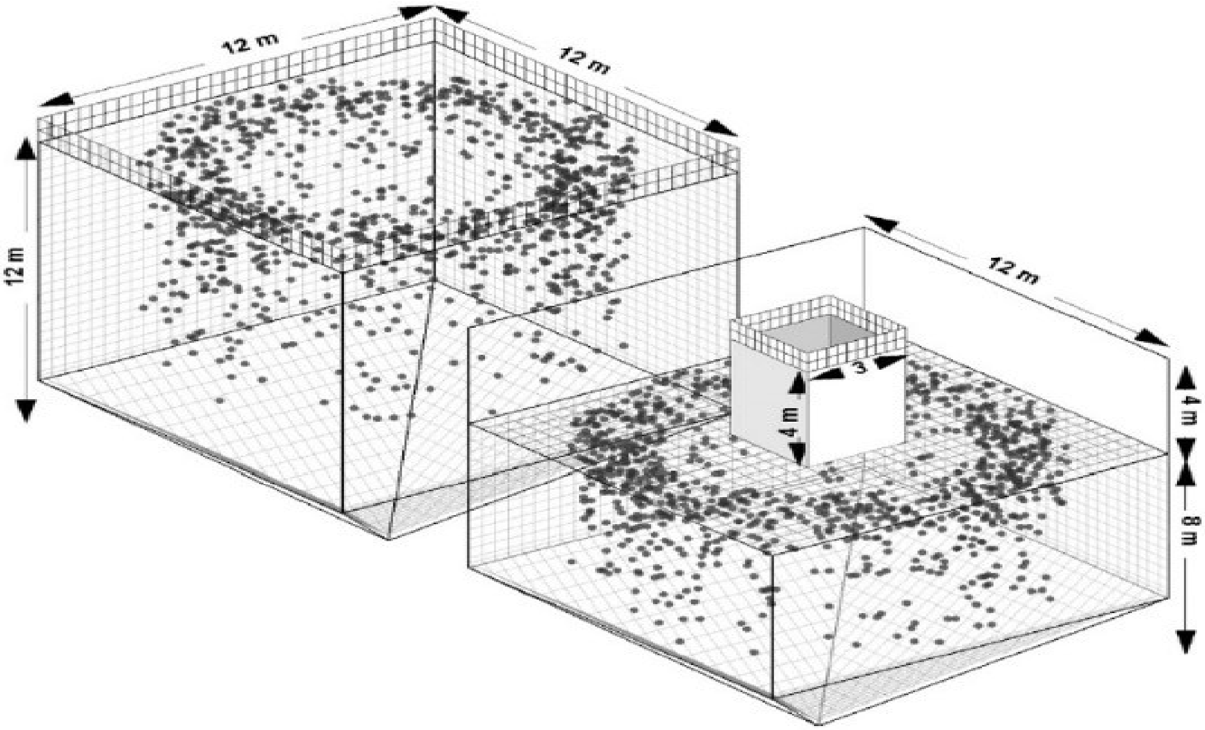


Figure 13. Snorkle sea cage model (Lars Helge Stien et al., 2016).

7.3. Closed floating cage technology

Transfer of production from sea to onshore sites or production in closed, floating sea cages have been suggested as a possible solution to the problems with sea lice. Production in closed confinement systems may also result in better controlled rearing conditions and more effective production. Closed floating cage technology is another innovative solution which has been studied for almost three years (Figure 14). Studies conclude that farming Atlantic salmon in closed, floating cages with water intake at 25 m offers an effective protection against sea lice. Moderate to high sea lice abundance in reference groups in open cages confirmed the presence of infective sea lice copepodites in the surface water around the cages. In the closed cages, sea lice were only recorded after fish had been moved to cages with well boats, or when the cages were stocked with fish transferred from open cages. When fish were exposed to sea lice in the closed cages, the recorded abundance was low and showed no signs of sea lice reproduction within the cages. Furthermore, records of mortality and growth during the test period indicated that production in closed sea cages is possible without adverse effects on survival or growth rates (Nilsen et al., 2017).

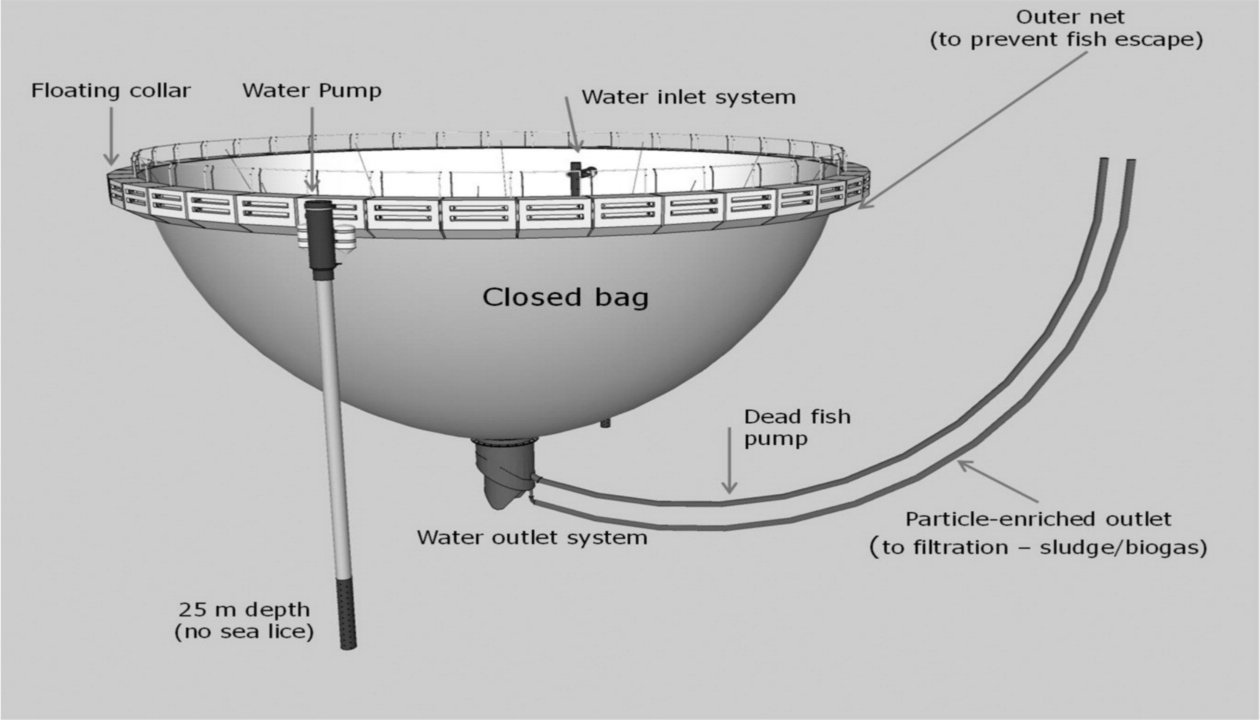


Figure 14. Closed floating cage model (Nilsen et al., 2017).

7.4. Skirt around Salmon sea cage

The ultimate solution to the problem of salmon lice is to prevent physical contact between the infective sea lice larvae (copepodites) and the salmon host (Lars H. Stien et al., 2012) . Management of water quality by pumping and filtering water into land-based rearing systems or fully enclosed sea cages will certainly prevent physical contact. However, both of these approaches are at an early development stage and depend on cost-effective technological solutions and methods to meet the biological needs of the fish. A simpler solution to this critical problem that can be implemented in conventional sea cages has recently been proposed. The salmon lice copepodites are typically found near the surface during daylight. Salmon held at 0-4 m depth developed higher infestation than salmon held at 4-8 m and 8-12 m depth. The salmon lice copepodites position itself in the upper water column to increase encounter probability with a potential host. It is therefore hypothesized that putting a tarpaulin around the upper few meters of a sea cage (a skirt) to block the surface water from entering the sea cage will reduce lice infestation rates on the farmed salmon (Figure 15). The skirt restricted free water flow and since the fish aggregated near the surface this resulted in detrimental oxygen levels even though the skirt only constituted 3 m of a 45 m deep sea cage. The present scenario must be considered in further investigations of skirts to reduce the exposure of farmed salmon to sea lice. Systematic measures of environmental properties, such as temperature and oxygen levels, are necessary prerequisites if a skirt is to be used. Possible remedies are oxygen permeable skirt fabrics, water pumping systems, oxygenation systems and the possibility of rapidly detaching the skirt if the oxygen saturation decreases below acceptable levels (Lars H. Stien et al., 2012).

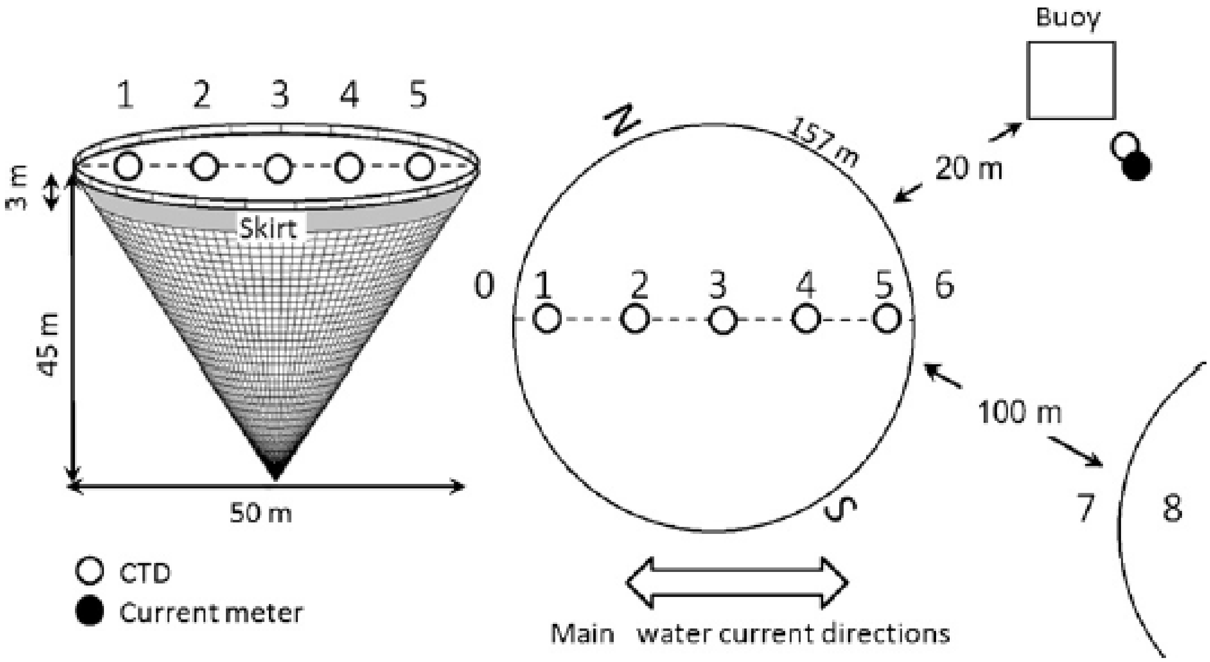


Figure 15. Skirt around a salmon sea cage (Lars H. Stien et al., 2012).

7.5. Thermal Technology

Another technology which is applying by Steinsvik company to treat sea lice, is thermal technology.

According to Laastad (2018), Thermolicer is a simple and environment-friendly lice treatment that has proven to be more effective than traditional treatment methods with chemicals and medicine. The Thermolicer herds and pumps fish into a processing loop for 25 to 30 sec. Thermolicer briefly bathes the fish in lukewarm seawater, which – because lice are sensitive to sudden changes in temperature – causes the lice to die and fall off the fish. Afterwards, the lice are collected and destroyed (Figure 16).

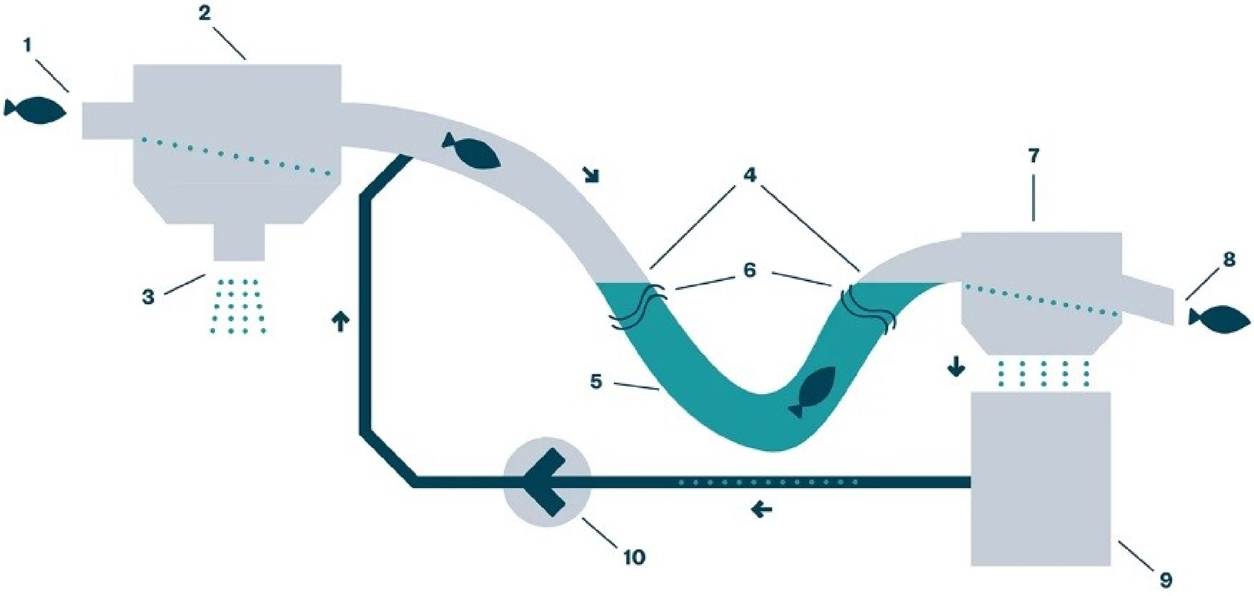


Figure 16 Thermolicer model (Laastad, 2018)

How it works, as summaries in Figure 16:

1. Fish enters Thermolicer
2. Water separation
3. Sea water filtered and released
4. Fish exposed to lukewarm water
5. Treatment loop
6. Water surface
7. Water separator for treatment water
8. Fish exits the system
9. Heated water circulated for filtration, aeration and reheating
10. Treatment water pumped back to treatment loop (Laastad, 2018)

7.5.1. Concrete benefits

The Thermolicer can be used for treatment of fish on a commercial scale. The system only uses heated seawater to treat fish. This reduces pollution around fish pens and provides an alternative that can counteract increasing drug-resistance in lice today. The Thermolicer fits on a boat or a barge, and each machine can treat up to 90 metric tons of fish per hour, depending on ambient sea temperature and local conditions. After the fish has been treated it can be sent back to the same cage or to an empty cage (Laastad, 2018).

7.5.2. Market potential

Lice is an issue for fish farmers worldwide. A health report published by the Norwegian Veterinary Institute in 2018 shows that the preferred method of non-medicine lice treatment is heated water. The report shows that there was an increase of non-medical treatment of 21 %, with 68 % of that treatment being thermal de-licing. Steinsvik is a world-leading technology supplier to the global aquaculture industry. The Thermolicer can be used by fish-farmers in salmon-producing areas and service companies to the salmon industry worldwide (Laastad, 2018).

7.6. New seawater-based production technologies

Currently, there are a number of different concepts, including enclosed or semi-enclosed marine farms, in the testing phase. The aim of these concepts is to create a physical barrier between the enclosed fish and the external environment. Among the various concepts, two main strategies are under testing:

- open cage constructions sited offshore (Figure 17)
- various forms of enclosed or semi-enclosed cages sited in sheltered localities (Figure 18)

The first priority has been to identify technologies that prevent settlement of salmon lice. Completely enclosed cages effectively prevent lice infestation, while other systems with partial enclosing and/or which possess the ability to be lowered in the water column provide varying degrees of protection. Enclosed or semi-enclosed farms provide a greater degree of security against fish escapes and greater opportunities for collection of waste products as compared to open cages. Common to such systems are the environmental and water quality challenges presented by internal currents, temperature, biomass and feeding. There is a need for research and increased experience of the interplay between production intensity, environment and fish welfare. These challenges will have to be addressed before these systems can be successful. Open, offshore cages, similar in shape and operation to inshore farms, achieve lower lice settlement by moving the fish away from the heavy infection pressures associated with coastal currents. The hygienic status and fish welfare aspects of such farms have not yet been fully documented (Lillehaug, Brun, Nilsen, & Hjeltnes, 2018).

Figure 17. Offshore farm (SalMar)

Figure 18. Closed-containment salmon farming in Norway (fly, 2017).

7.7. Proactima

Another company in Stavanger which recently (May 2019) announced a solution to treat salmon lice, is Proactima company. The company saw that water flow models could also be used and further developed to alert the lice spread so as to be able to prevent the problem. The focus here is how the breeders can protect themselves against salmon lice and how they can prevent the spread itself. Their solution allows to develop a uniform and proactive salmon lice strategy for Rogaland which is totally unique. Weekly, all breeders had to report how much lice they had per fish, they reported on temperature, number of fishes, location and much more. In collaboration with Danish Hydrological Institute, Proactima retrieves data from sources about the weather, fresh water from the Norwegian Water Resources and Energy, the number of adult salmon lice that produce eggs and other data that are important for how the lice eggs move in the sea. Together, this becomes a large, mathematical model that, among other things, tells where lice come from and where it flows.

The unique feature of the Proactima simulation is that they can see five days ahead and five days backwards, how lice eggs move with wind and weather (Figure 19)(Garlid, 2019).

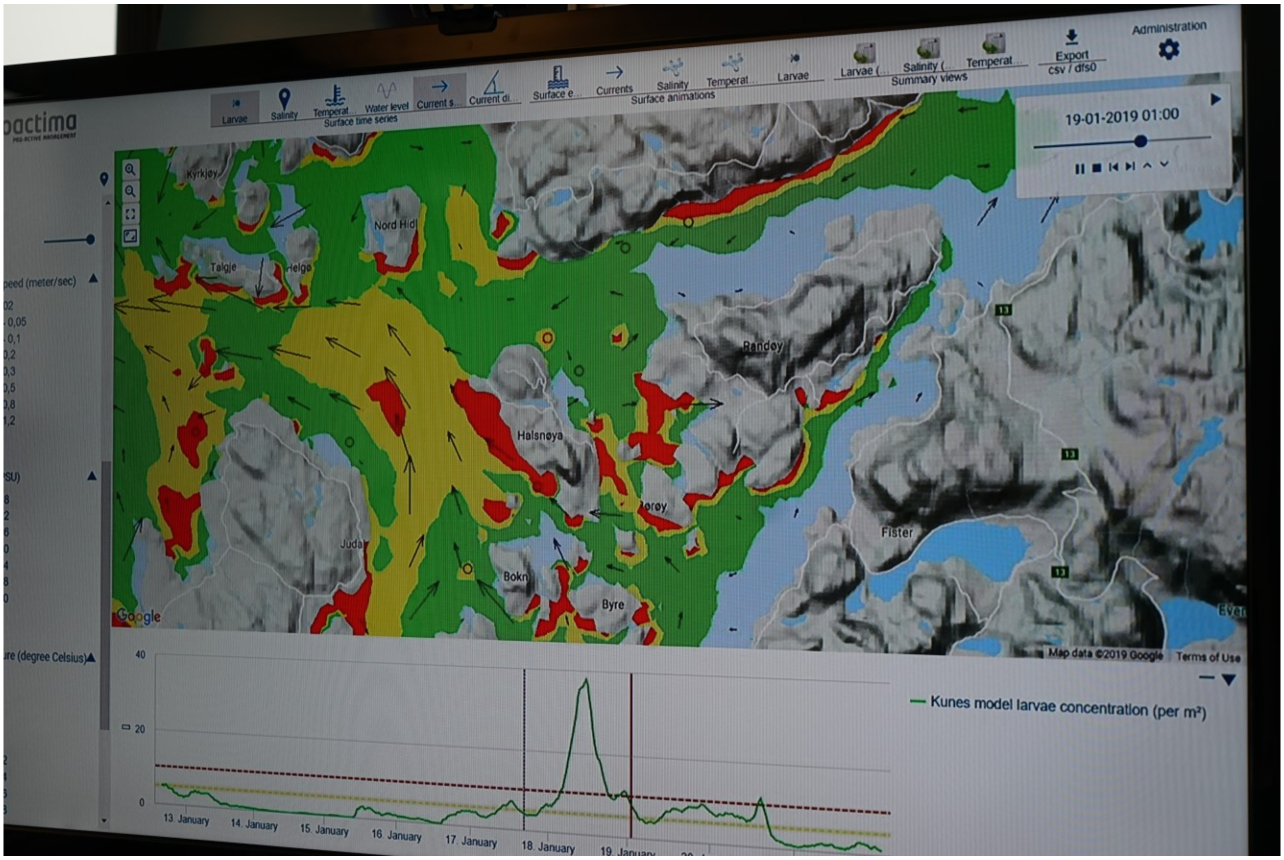


Figure 19. The unique feature of the Proactima simulation (Garlid, 2019).

8. WELFARE CHALLENGES RELATED TO SALMON DE-LOUSING

Salmon lice is also an ecological problem, since the lice multiply in fish farms, and then spread to the wild salmon population. Chemical treatment is used to combat the lice nowadays but use of biological measures such as cleaner fish has increased lately due to more development of resistant lice to the chemical treatment. However, moderate genetic variation has been shown for resistance to the salmon lice, and thus it may be possible to reduce problems caused by lice through selective breeding programs (Olesen et al., 2011).

The word ''welfare'' is derived from well plus fare, i.e., how well (or dignified) an animal ''fares'' (travels) through life. How well is an animal able to regulate its biological functions in relation to its environment? A function-based definition of animal welfare could be: The welfare of an animal is its state as regards its attempts to cope with its environment. Other definitions focus on an animal's subjective experience or awareness of its condition (feeling based) and/or on whether it can lead a natural life (nature based). Hence, the term ''animal welfare'' applies to both the mental/emotional and physical health (from an objective standpoint) of the individual animal or the animal's condition while trying to cope with its environment. The term also includes behaviour, as well as physiological and immunological factors (Olesen et al., 2011).

Prevention of high levels of lice production is an important environmental target for the industry. In some cases, the number of lice in individual farms is so high that it presents a direct welfare challenge to the farmed fish. Such cases were observed in 2016, where, if the louse burden is held below the maximum treatment threshold of 0.5 adult female lice per fish (a limit set to hold infection pressure towards wild salmon low), there will be a low degree of direct impact on the welfare of farmed fish. In addition, the problem of high lice numbers is not as straightforward as it seems. De-licing has also been identified as a considerable challenge to fish welfare, particularly if the fish are weakened by other infections. Special consideration must also be given to the welfare of cleaner fish species during lice treatment, or these fish may die during lice-treatment. In addition, salmon lice display, to an increasing degree, significantly reduced susceptibility to most available chemical treatments. As a result, the problems brought about by current solutions has led to a rapid expansion of novel nonmedicinal treatments. In 2017, has seen further increases in use of thermal and mechanical de-licing in particular. Thermal de-lousing requires transfer of the fish to a water bath (usually 29-34 ºC, dependent on seawater temperature) for approximately 30 sec (e.g. Figure 16). There are two main systems used for thermal de-lousing, and the most popular is that one which uses a paddle wheel to transport the fish through the water bath (Gismervik, Gåsnes, Nielsen, & M. Mejdell, 2018).

While research has shown that such temperatures are generally painful to fish, and specifically research is done by Hoddevik and Press (2019). According their research, results show that farmed salmon have clear pain behaviour when debilitating in hot water at 28-38 °C. In the experiment researchers saw that the salmon changed behaviour overall when they transferred it to vessels with water temperatures from 28 °C and higher. It was a very clear pain response from the first moment. The fish swam significantly faster than control fish and collided in the vessel walls, splashed in the surface and eventually lost body control (Hoddevik & Press, 2019).

Also, it was observed by fish health services that salmon had displayed significant brain haemorrhages following the thermal de-lousing in both apparently healthy large fish that died and fish appearing moribund after treatment. Gas supersaturation and poor water quality (particles and slime) are commonly identified culprits in such treatment chambers. Mechanical de-lousing represents various techniques to physically flush the lice from the skin of the salmon. Currently, there are three different methodologies in use; one based on water flushing alone, one based on a turbulent water current, and another which combines water flushing and physical brushing. Information from the Norwegian Food Safety Authority indicates that the final technique had been improved during 2017 to ensure better fish welfare, and that the brushes now direct the salmon towards the water jets rather than physically brush the lice from the salmon. The manufacturer's homepage continues to state, however, that the technology 'brushes clean' the salmon. Despite improvements in the methodologies, injuries including scale loss and skin bleeding are associated with the different forms of mechanical de-lousing (Gismervik et al., 2018).

In addition, a common factor involved in all non-medicinal lice treatments is the need for crowding of the fish prior to pumping into the de-lousing system. Crowding is in itself known to represent a considerable welfare risk. Thermal, mechanical and freshwater treatments involve careful handling to prevent a series of stressful situations as well as direct physical injury to gills, fins, eyes, skin etc. Additional stressors include changes in water quality e.g. fall in oxygen levels or gas supersaturation. Water temperature may also be decisive in relation to ulcer development. De-lousing systems are relatively new and still developing. Available documentation regarding fish welfare in these systems is minimal and mostly produced during early developmental phases. Thus, a comprehensive overview of welfare problems and risk factors associated with non-medicinal de-lousing is not yet available. During 2017, the Norwegian Food Safety Authority received 963 reports of welfare-related incidents about the growing sites of salmon. Of these reports, 625 of them were related to de-lousing and the majority to non-medicinal treatments and handling (Hjeltnes, Bang-Jensen, Bornø, Haukaas, & Walde, 2018).

The same report points out severity and extent of the reported incidents were varied, as different companies may have different thresholds for reporting of such incidents. In comparison, the Norwegian Food Safety Authority received 400 reports of de-lousing-associated mortality (> 0.2%) during 2016. An increase in number of reports received was observed from the middle of 2016, following a general reminder to the industry of the compulsory nature of reporting by the Norwegian Food Safety Authority, which partially explains the increased number of reports in 2017 compared to 2016. Another explanation for the increase could be that welfare problems are growing with the increased use of nonmedicinal methods. The steady reduction in the use of medicinal anti-louse treatments continued in 2017, despite limited continued attempts in utilizing increased doses and exposure times. Such experiments, which can lead to both acute poisoning and serious welfare consequences, has occurred less often following an increase in field checks by the Norwegian Food Safety Authority (Gismervik et al., 2018).

As far as combination treatments are concerned, the authorities require documentation of the efficacy of mixtures of various active ingredients to be improved before use. The additive effects of other management routines such as net changing, movement of fish from cage to cage or between sites, and well-boat transport, give grounds to believe that the tolerance limits of the fish have already been exceeded in many farms. This is particular problem in relation to the significant increase in use of non-medicinal lice treatments in 2017. The efficiency of non-medicinal methods for removal of lice depends on many factors, including the basic principle behind each treatment method, how the machine is adjusted on the treatment day (e.g. water pressure in mechanical systems and temperature in thermal systems), exposure time (freshwater and thermal), model and eventual modifications to the original specification (Gismervik et al., 2018)

Other factors such as crowding, and the number of fishes treated per hour also have an impact on success rate. To find out whether field experiences indicated differing success rates between the various non-medicinal treatments, respondents were asked to estimate the average success rate for removal of motile and sexually mature lice following thermal de-lousing, the various flushing systems and freshwater treatment. Given the relatively common occurrence of acute mortality episodes in association with thermal de-lousing, there is a considerable concern to whether this current method is an acceptable means of treating fish with regards to fish welfare. Injuries/side effects registered in association with thermal de-lousing include panic reactions in which many individuals collide with the walls of the treatment unit during and after treatment. Moribund fish with protruding eyes, bleeding eyes and brain and palate haemorrhage are also common observations (Hjeltnes et al., 2018).

Acute mortality has been associated with Cardiomyopathy Syndrome (CMS) or gill bleeding and other underlying diseases such as yersiniosis, gill inflammation, and HSMI (Heart and skeletal muscle inflammation). Good fish health prior to de-lousing is therefore extremely important. Other factors of importance include duration of pre-treatment fasting, crowding and pumping technologies, the last of which pertaining differing fish sizes in particular. Crowding may also cause scale loss and skin bleeding, and it is therefore difficult to distinguish if such injuries were caused by the de-licer or because of crowding. Relatively long frequent periods of crowding have been the norm in relation to mechanical and thermal de-lousing, and unless less damaging methods of crowding are developed, crowding-associated injury will continue to accompany these de-lousing methods. Mechanical de-lousing is also known to have resulted in injury. Gill and operculum injuries have been attributed to non-medicinal treatments (Hjeltnes et al., 2018).

9. MEDICINE TO TREATMENT SEA LICE IN NORWAY

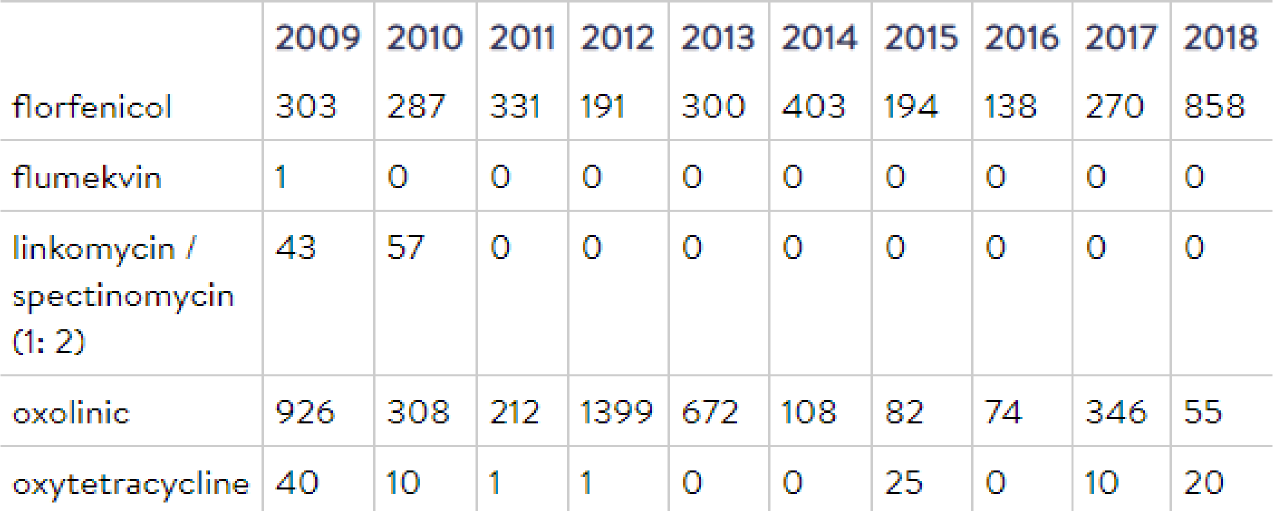
According to Norwegian Institution of Public Health, Norwegian fish farms used less medicine to treat salmon lice in 2018 in comparison to previous years. The studies and reports confirm that the aquaculture industry has changed its strategy: salmon lice are now increasingly being removed by various methods, such as hot water, fresh water and mechanical removal. The low consumption gives hope that the resistance situation can improve in the long term. Table 1 lists the different types of medicine used to treat salmon lice in Norway, from 2009 to 2018. Data are based on reported sales to the Norwegian Institute of Public Health from pharmaceutical wholesalers and feed companies. Table 1 shows that the use of the active substances azamethiphos, diflubenzuron and teflubenzuron has not been decreased, measured in kg, since 2008. Cypermethrin (a pyrethroid) was not used in 2018, while the use of deltamethrin was at the lowest since the drug was put into use late in the 1990s.The use of hydrogen peroxide has not been lower since 2012 (FHI, Horsberg, & Bangen 2019)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
azametifos	1884	3346	2437	4059	3037	4630	3904	1269	204	160
cypermetrin	88	107	48	232	211	162	85	48	8	0
deltametrin	62	61	54	121	136	158	115	43	14	10
diflubenzuron	1413	1839	704	1611	3264	5016	5896	4824	1803	378
emamektin	41	22	105	36	51	172	259	232	128	87
teflubenzuron	2028	1080	26	751	1704	2 674	2509	4 209	293	144
hydrogen-peroksid (100%) (tonn)	308	3071	3144	2538	8262	31577	43246	26597	9277	6735

Table 1: Average medicine to treat Salmon lice in Norway (kg active substance/Year) (FHI et al., 2019)

9.1. Sales of antibiotic

According to Norwegian Institution of Public Health's report, sales of antibiotics for use on farmed fish in Norway are still low, although there was an increase in 2018. As shown in Table 2, sales have varied in the period 2009 - 2018.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
florfenicol	303	287	331	191	300	403	194	138	270	858
flumekvin	1	0	0	0	0	0	0	0	0	0
linkomycin / spectinomycin (1: 2)	43	57	0	0	0	0	0	0	0	0
oxolinic	926	308	212	1399	672	108	82	74	346	55
oxytetracycline	40	10	1	1	0	0	25	0	10	20

Table 2: Sales of Antibacterial (kg/Year)(FHI et al., 2019).

There has been a significant increase in the use of Florfenicol in 2018, in comparison with the use in previous years. However, compared to last year, there is an increase in the amount of antibiotics used for fish farms in 2018, from 535 kg to 871 kg. Of this, 764 kg (about 88%) went to treatment in three fish farms. In all three plants the average weight of the fish was high (3-3.9 kg), which means that the amount of antibiotics needed for a cure becomes larger (FHI et al., 2019).

10. DISCUSSION AND CONCLUSSION

The fish farming is an important industry for supplying food for people. Sea food is a great resource for feeding population, specifically for the next coming decades, as world population is expected to reach 9.7 billion by 2050.

Norway endorses the UN Sustainable Development Goals, and The Norwegian Seafood Federation's sustainability goals for the aquaculture industry are based on those goals. To have a sustainable production, the industry needs to reduce mortality of fish in the farms and reduce the cost of fish farms. Sea lice is one of the greatest environmental challenges for salmon farming industry. Salmons, which have been attacked by lice, *Lepeophtheirus salmonids* (*Krbyer*), emerged as a problem soon after the establishment of the industry in the 1970s, as it is a serious threat to Atlantic salmon smolts migrating through Norwegian fjords and coastal areas. Since Salmon lice are recognized as a problem, many different solutions have been applied, and researchers are still making an effort to find the best sustainable solution. Proposed methods can be divided into medicinal and mechanical.

The efficiency of non-medicinal methods for removal of lice can depend on various factors, including the basic principle behind each treatment, how the machine is adjusted on the treatment day (e.g. water pressure in mechanical systems and temperature in thermal systems), exposure time (freshwater and thermal), model and eventual modifications to the original specification. Other factors, such as crowding and the number of fishes treated per hour, also have an impact.

In order to find out whether field experiences indicated differing success rates between the various non-medicinal treatments, the respondents were asked to estimate the average success rate for removal of motile and sexually mature lice following thermal de-lousing, various flushing systems, and freshwater treatment (Gismervik et al., 2018).

Norwegian companies, which work with sea lice treatment, are very pioneer. Some of the innovative solutions for salmon lice treatment are identified in this thesis. For example, Fishency is a company, which was established in 2017 in Stavanger. Their technology focuses on monitoring and prevention more than on treatment. The company is still in pilot test and has not entered into the market. So, it is not possible to compare the cost of flagship product to other solutions.

"Snorkle" sea cage is a study, which was conducted in autumn 2013 at the Institute of Marine Research aquaculture station in Austevoll, western Norway. The study highlights the substantial potential for preventing a significant level of sea lice infestation by using snorkel sea-cages on large salmon raised at commercial stocking densities during autumn (Lars Helge Stien et al., 2016). Closed floating cage technology has also been experimented in Norwegian and results show that when sea lice were introduced into closed cages, no signs of reproduction or continuous infection were recorded. Preliminary production data indicates that production in closed cages could give acceptable survival and growth rates compared to traditional open cages. Further studies on technical stability, water quality, fish welfare and biological and economical results are necessary to evaluate the sustainability of this new cage technology (Nilsen et al., 2017). Skirt around salmon cage is other proposed solution. However, according to the obtained results, the abundance of fish in the enclosed skirt volume caused a decrease in the oxygen levels in comparison to the much higher oxygen levels observed before skirt deployment, after skirt removal, and inside the neighbouring control cage (without skirt) when the skirt was operational (Lars H. Stien et al., 2012). So, in this case, though the decrease in sea lice is significant after operating skirt, but the decrease in level of oxygen cannot be neglected. By using oxygen producer devices in the farm, the result could be satisfying.

In thermal technology, which is being applied by Steinsvik company to treat sea lice, Thermolicer briefly bathes the fish in lukewarm seawater, which – because lice are sensitive to sudden changes in temperature – causes the lice to die and fall off the fish. However, this technology is neither medicinal nor mechanical, and the company believes that it is the most sustainable solution in salmon lice treatments, but there is some discussion regarding welfare issues. According to Hoddevik Sunnset (2011), farmed salmon have clear pain behaviour when debilitating in hot water at 28-38 °C. The salmon changed behaviour overall when they transferred it to vessels with water temperatures from 28 °C and higher. The fish swam significantly faster than control fish and collided in the vessel walls, splashed in the surface and eventually lost body control. So far, it is also a discussion among scientists whether fish feels pain or not. So, it is early to conclude that thermal de-licing technology is a sustainable solution.

In the last part of the study, the dosage of chemical medicine, which is being applied in Norwegian fish farms, is reported based on a FHI report. It shows that use of hydroperoxide, which is being applied to remove sea lice, has been reduced in 2018 than that in 2017. However, there was a significant increase in the period of 2014 to 2016, but the decrease in 2017 is noticeable. Florfenicol and oxytetracycline are antibiotics, which have been used in 2018 much more than 2017. This amount has been applied in three fish farms because of the sudden increase in salmon's weight. It seems that this amount is too much for just three farms, and it didn't report which farms applied it.

Although there is evidence that antibiotic resistance can be selected for in normal therapeutic use in aquaculture, the risks of transfer of such resistance to human consumers by any of the possible routes appears to be low (Alderman & Hastings, 1998). So far, according to the data extracted from scientific papers and innovative companies, a sustainable solution might be the one which consider: fish welfare, cost of solution, mortality of fish in the farm after treatment, high technology, flexibility to develop based on density of farm and temperature of water. So far, there is not any solution as a product who consider all the factors above.

11. RESTRICTIONS AND FUTURE PERSPECTIVE

The lack of enough research and published data was the most challenging part of the study. Since sea lice treatment is a sensitive subject in Norway, some scientists that I contacted were afraid of sharing the data or knowledge about their research and job. Also, the company, which I contacted and asked for a face to face meeting, refused to have meetings. Therefore, I had to trust and apply all the information and data, which are officially published as a scientific paper or the information which are released by the companies' website or reports. I recommend researchers, who are interested in the subject, work more about the effect of medicinal treatment of sea lice on the quality / taste of fish farm's salmon and if in long term use of medicine has effect on human body. Also, it seems that more studies, research and innovation in nonchemical medicine (nature based) in salmon lice treatment are really needed.

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