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The Cost of Sea Lice and Its Implications for the Future of the Norwegian Aquaculture Industry

A Study on Sea Lice and Recommendations for the Government to Reach Its 2050 Goal

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Executive Summary

The Norwegian government has stated its goal to reach a production level of five million tons of farmed salmon by 2050. Today, the country produces approximately 1.2 million tons. Sea lice have become one of the biggest obstacles for continued growth in the Atlantic salmon industry in Norway. The costs related to sea lice treatments were estimated to NOK 4/kg of harvested fish in 2016, while they were calculated to NOK 1.5/kg in 2011.

This thesis aims to examine the indirect cost related to lice and its implications for the government's 2050 goal. Indirect costs incur from reduced growth of biomass caused by lice infestation of salmon. Based on the quantitative analysis of the indirect costs, we build a qualitative analysis to discuss and suggest a direction for the government to reach the 2050 goal.

Using data from farms in Norway from January 2013 to December 2016, we estimate the impact of lice in terms of biomass growth. The results show that indirect costs have increased compared to earlier studies. On average, Norwegian farmers experience a loss of NOK 4.40/kg or 9.5 per cent of revenues to reduced biomass growth. The qualitative analysis suggests that the most critical drivers to shape the future of the industry are the government's regulations and technology development and adoption by farmers. Four different scenarios developed by these two drivers illustrate the salmon aquaculture industry in 2050 where two of the scenarios indicate the possibility of increased production.

Depending on the level of lice regulations, we recommend two different actions. With relaxed regulations regarding lice, different incentive schemes can encourage the farmers to cope with the problem with autonomy. Whereas, when the regulation is relatively stricter, the government should be able to provide the readiness for the farmers before the intensified regulation enforcement of lice.

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1. Introduction

1.1. Overview of the Paper

Sea lice is one of the biggest challenges to the salmon farming industry in Norway, and the government's goal to reach five million tons of production by 2050. The industry has seen a rapid growth over the last decades, but has experienced a stagnation in annual biomass level in the recent years (Statistics Norway, 2017a). Many experts are relating this to the increase of sea lice levels in Norwegian salmon pens (Torrissen et al., 2013). Sea lice attach to host salmon and feed on its skin. This process stresses the fish and causes a reduction in fish growth and death in some cases (Thorstad et al., 2015). The number of sea lice per salmon has increased steadily over the last two decades, and an important reason for this is the increasing level of farm densities, which allows the spillover of lice from one farm to another (Abolofia, Asche, & Wilen, 2017). Another reason for the phenomenon is rising sea temperatures as this improves the living condition of lice.

Sea lice entail economic loss for the salmon farmers and it is difficult for the farmers to quantify the exact loss from the lice. Due to the regulation of restricting the level of maximum average of 0.5 female lice per salmon, farmers must often harvest their stocks well before the fish reach the preferred weight of 4-5kg (Marine Harvest, 2017a; Norwegian Ministry of Trade Industry and Fisheries, 2012). Furthermore, we interviewed professionals in the aquaculture industry when drafting the thesis and found that a big problem for many farmers is to quantify the total costs of sea lice. In response, the first section of our analysis measures the total loss for farmers due to sea lice. The results from the first analysis set the basis of the future scenario analysis that can provide potential guidelines for policy makers.

The total costs consist of direct costs and indirect costs. We specify the direct costs as the direct kroner outflow of money spent on delousing treatments, and the indirect costs as the revenue lost due to the reduction in biomass growth. The direct costs related to treatments of lice-affected salmon were measured to account for NOK 5 billion in 2016 (Nofima, 2017; PwC, 2017), however, not so many attempts have been observed to estimate the indirect costs. Direct costs have increased significantly over the last decade. Therefore, it is important to examine whether this increase in treatment spending has led to a decrease or increase of indirect costs for the Norwegian government to reach its stated goal. With the quantified results, farmers can be more alert with the seriousness and urgency of the problem.

The quantitative analysis shows that the indirect costs are increasing despite the recent surge in treatment costs. Using a biomass growth model, we find that there are differences between the different regions in Norway, classified as South, Central and North. In the first part, we find that the indirect cost a farmer in the South can expect to incur is NOK 7.45/kg or 16.09 per cent of expected revenues during a typical 17-month production cycle. The same numbers in the North are NOK 2.09/kg and 4.51 per cent. These numbers are interesting as they show that the impact of lice varies depending on different region specific factors. For example, in the North, temperatures and farm density are lower, while farm size is larger. However, it is the opposite in the South. The coefficients of the interaction terms in our analysis support this, as shown later. The second part of the quantitative analysis is to calculate the direct costs for our dataset for the different regions, which gives us a total expected cost in the South of NOK 9.17/kg or 18.86 per cent of revenues, and NOK 3.66/kg or 7.52 per cent in the North.

The heterogeneity between regions is in line with a previous study by Abolofia et al. (2017) where the researchers used data from 2005 to 2011. When comparing the expected costs, we see that the indirect costs have increased significantly over the few years between the two datasets as Abolofia et al. (2017) find that a farmer in the South can expect costs of NOK 4.80/kg or 13.10 per cent of expected revenues. The corresponding numbers in the North are NOK 1.07kr/kg and 3.02 per cent.[1]

The problem of the increase in total costs for lice implies that the research should further examine and propose the potential solutions for the future. Therefore, the aim for the qualitative analysis is to provide the relevant stakeholders with valuable insights. The analysis also suggests cost effective and efficient policies for the government for its long-term goal of five million tons of salmon production in 2050. We use the PESTEL framework to provide an overview of the main factors of the salmon industry, which lets us identify the most relevant potential future scenarios.

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[1] The NOK numbers are adjusted from the dollar values that Abolofia et al. (2017) are using to measure per kilo cost. Their original numbers are $0.67/kg and $0.15/kg for South and North respectively. We adjusted these values using the average annual exchange rate from 2013-2016 of $7.16/NOK. In the former article, the authors used an exchange rate of $5.88/NOK.

The PESTEL and scenario planning analysis conclude that the government can adjust the current regulations and introduce new measures. The most relevant signals identified through the PESTEL framework include governmental focus on renewable resources, international trade dynamics, market dynamics, industry characteristics, demographic features, technology development, environmental impact, media, government initiatives and regulation demand for other concerns, among others. We select the most critical five drivers, and the least related two among those, which are technology adoption and government regulation, are the base axes for developing the scenarios. The different four scenarios suggest different landscapes of the industry depending on the technology adoption level and the intensity of government regulation regarding the lice level. Two of the scenarios indicate potential growth of the production level. Depending on the intensity of lice restrictions, the government can adjust its regimes either by offering incentive for salmon farmers or by supporting them to prepare for the regulation enforcement.

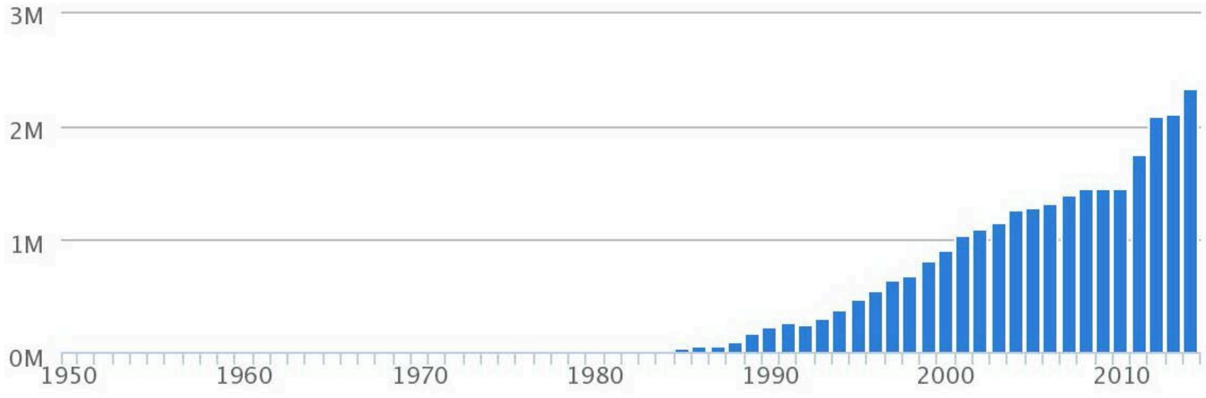
The outline of this thesis is as follows. In the next chapter, we describe the main characteristics of the salmon industry, a detailed background on sea lice and the different treatment methods used in Norwegian aquaculture today. Moreover, we also present other findings from different literatures within the main topic of our paper. The following chapter consists of two different methodology sections where we first conduct the quantitative analysis of the indirect and direct costs of sea lice. This section begins with the introduction of the model of the analysis, and then we present the data and end with the analysis. Next, the qualitative analysis' main findings highlight the four different scenarios illustrated by critical drivers from the PESTEL framework. Finally, we measure the current policy tools for resolving the lice problem and round up with a discussion of the findings of our paper that explain the implications and recommendations for the policy makers. In addition, limitation of the paper and further study suggestions are mentioned at the end.

1.2.Background

1.2.1. Salmon Farming Industry

Global fish consumption is not only three times higher than it was in 1980 but also predicted to have a rapid growth in the future (FAO, 2017a). Production is also following an increasing trend. Atlantic salmon is renowned as one of the most beloved seafood products, and 70 per cent of the salmon is farmed due to its scarcity in the wild (GLOBEFISH, 2017; Marine Harvest, 2017a). The growing production of farmed Atlantic salmon is illustrated in figure 1.

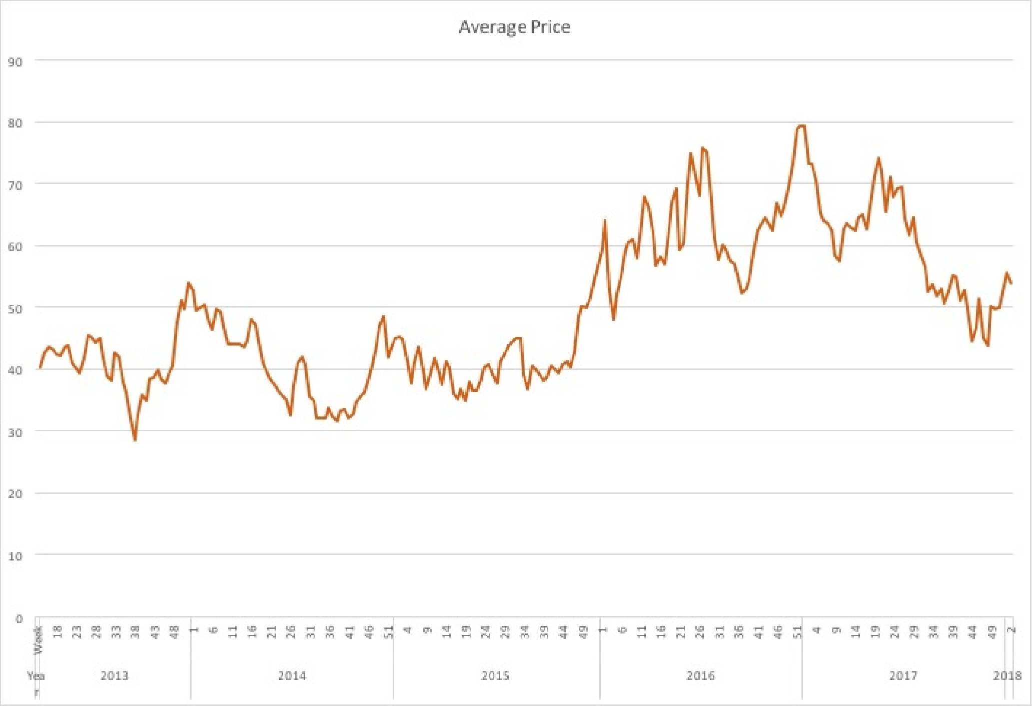
Figure 1: Global Aquaculture Production for Atlantic Salmon



Source: (FAO, 2017b)

The price of farmed salmon has been fluctuating as illustrated in figure 2, yet shown an increasing trend, reaching NOK 70 per kg in late 2016. Global aggregate demand for the product is growing (FAO, 2017c). On the supply side in the recent two years, the price surged mainly from increasing production costs, driven by higher feed production costs and sea lice (EY, 2017; PwC, 2017). Moreover, there has been a supply shortage of the major producing countries, from algae bloom and decreased smolt release in Chile in 2016, and a forced harvest due to lice in Norway in 2015. However, from mid 2017, the price dropped possibly following a production spike in the European Union. Price changes are forecasted to be more stable in the coming years due to strengthened regulations such as regarding parasitical diseases in the biggest salmon production countries (GLOBEFISH, 2017).

Figure 2: Average Price for Salmon



Source: Nasdaq Salmon Index

Due to biological and natural constraints such as seawater temperature requirement, only certain countries have sufficient conditions for salmon farming, including Norway, Chile, UK, Faroe Islands, Ireland, North America, New Zealand and Tasmania (Marine Harvest, 2017a). Among these countries, Norway is considered as one of the pioneers in salmon aquaculture with its long coastline, which includes islands and deep fjords and extends for more than 83,000 kilometers. The cages in Laksåvika on Hitra in Norway that Ove and Sivert Grøntvedt set out in 1970 are regarded as the world's first fish cages. Norway exported 980,000 tons of salmon in 2016 which converts to sales value of NOK 61.4 billion, as the biggest producer in the market (Norwegian Seafood Council, 2017). The Norwegian government wants to remain the world's leading seafood nation, and envisions that its seafood production can be increased to five million tons by 2050 (Norwegian Ministry of Fisheries and Coastal Affairs, 2013).

The value chain of farmed salmon consists of different segments. To begin with, the journey of commercial salmon products starts from egg and spawn of the brood stock, through smolt to edible size of fish. Once the fish reach the market size, the products are processed and distributed in domestic and international markets (EY, 2018). Along the production process, there are breeding, hatchery, fish farming, logistics and transportation, suppliers of equipment and services, processing, and export and trade (Finne, 2017). Our research is focusing on the cost effects of lice in the fish farming process of the value chain in salmon farms.

The major current challenges for the industry come from the increasing production costs. The factors for the increase in production costs consist of fish feed as well as the costs accompanied by parasites and fish disease. Feed costs account for nearly half of the production cost, and have been increasing sharply (The Norwegian Directorate of Fisheries, 2017). This is mainly due to the increased USD/NOK exchange rate, with United States being the biggest fish feed ingredients exporting country to Norway. Furthermore, there is an overall price surge of marine feed ingredients, which struggle to keep up with the increasing level of aquaculture production (PwC, 2017). However, our paper's analysis is mainly focusing on the cost effects occurring from sea lice. Even though feed cost is a big part of the production costs, the complexity of the lice issue makes it a more interesting topic to examine.

While achieving its production goal, the government also aims to manage the industry in a sustainable way. The regulatory body has put out a number of policies stated in The Aquaculture Act (17 June 2005) and Food Safety Act (19 December 2003). The main regulation scheme stated in these laws includes the production licensing system. The Norwegian Ministry of Trade, Industry and Fisheries allocates the new licenses, and the Directorate of Fisheries administers them. Production is limited to maximum allowed biomass (MAB) of 780 tons (945 in Troms and Finnmark) per license. In addition, according to the Norwegian regulations, there should be on average fewer than 0.5 adult female lice per fish in a facility. If the limit is not satisfied, farmers should apply proper treatments or harvest the stock. However, the regulation also offers a flexibility for brood stock period and regions. Furthermore, the most recent policy is the so-called Traffic Light System, which came into effect in October 2017. In response to the media's criticism to the new license allocation, the Norwegian government suggested a predictable system for sustainable growth based on the environmental indicators. Thirteen separate production areas in Norway are given green, yellow or red lights as indicator for controlling the MAB volume per production area. The indicators are based on the risk of wild salmon being harmed by sea lice (The Ministry of Trade, 2015). We describe the system more in details in section 3.1.1. Lastly, the government has implemented development licenses, and green licenses as incentives for innovative projects to discover new solutions for sea lice (Marine Harvest, 2017a).

1.2.2. Sea Lice

Lepeophtheirus salmonis are the most common species of lice, which infect the farmed salmon in Norway. The parasite's survival and development are optimal in high-salinity sea water. Other driving forces of growth include water temperature, fish size, fish density, location, among others (Costello, 2006). The life cycle of L. salmonis involves non-feeding plaktonic larvae, infective planktonic copepodies, immature chalini on the host skin and mobile pre-adults and adults moving freely over the host skin (Hayward, Andrews, & Nowak, 2011). The level of damage varies according to the developmental stages of sea lice, as well as the density and size of the host fish. Studies have indicated that 0.1 lice per gram of fish body weight can already have deadly effects on host fish that are bigger than 10 grams (Costello, 2006; Wagner, Fast, & Johnson, 2008). These parasitic species feed on mucous, skin and blood of the fish, destroying the immune system of their host. Infected salmon is more vulnerable for secondary infection caused by fungi or bacteria and additional diseases (BarentsWatch, n.d.). Furthermore, infection affects the host's appetite, slowing down the growth. Sea lice have become an impactful problem especially because of the intensive salmon farming which offers better condition for parasite to grow and transmit with a year-round high density of hosts compared with natural conditions (Torrissen et al., 2013).

Various articles have presented the economic and non-economic impacts triggered by sea lice on farmed salmon as well as wild salmon. In this paper, the impacts on the farmed salmon are explained and how that might affect wild fisheries. To begin with, the effects are segmented into three categories; biological, economic and social.

Firstly, biological costs refer to the occurrence of particular health effects for farmed salmon from exposure to sea lice. The direct biological consequences of sea lice are characterized as wounds on the skin of the fish and increased level of stress from both the lice themselves and treatments. These further trigger higher mortality, reduced fish growth, weakened immune system, and lower feed conversion efficiency (Liu & Bjelland, 2014). The effects can convey negative impact to the neighbor farms (Torrissen et al., 2013), as well as the wild stock (Liu, Olaussen, & Skonhoft, 2011).

Our in-depth analysis for the impact of lice in section 2.1.4. especially concentrates on reduced fish growth. This slower growth also implies increased length of time to the market after lice and treatments. Furthermore, lice have become more resistant to chemical treatments, which can spread from farm to farm and region to region. As a consequence of cross-infection to wild fish, ecosystem can be also distorted (Liu et al., 2011). These biological impacts are ultimately connected and added to economic costs. For example, wound on salmon can lower the products' final market value. Higher mortality level, reduced growth in biomass, and weakened immune system can delay the process to reach the market, which might also trigger higher feed costs in the farm.

On top of that, the most significant and visible economic costs of sea lice where control on farm level is successful in preventing pathogenicity, are related to treatment among others. There are different sub-costs incorporated into different treatment methods. However, in general, expenditure on sea lice treatment consists of investments, alternative capital costs, extra manpower, insurance, depreciation, transportation, rents, among others (Marine Harvest, 2017a; Nofima, 2017). Furthermore, other economic costs can be explained by decreased quality and market value in terms of fish health, which can lead to market distortion from reduced production and change in consumption patterns. The use of parasiticides can also involve negative publicity about the product and its origin, which might lead to reduced potential exports and limit the industry growth potential (Costello et al., 2001). Eva Bratholm, the counsellor at the Norwegian Embassy in India from 2010 to 2012, highlighted the importance of the salmon aquaculture industry for Norway, by mentioning that “Norwegian salmon is an excellent ambassador for Norway abroad, and is widely used” (The Norwegian Seafood Council & The Norwegian Seafood Federation, 2011).

Lastly, social costs incorporate the effects of an activity on the social fabric of the community and well-being of the individuals and families(Business Dictionary, 2018). Sea lice can cause negative externality and decreased amenity value on both a regional and a global scale. Especially in Norway, fisheries and aquaculture make up a huge share of the national economy, thereby are important industries to create jobs ranging from suppliers, administrators to processors. The lice problem will create a bigger impact especially in certain small municipalities where the main source of income consist of aquaculture products (Internatonal Salmon Farmer Association, 2015). Moreover, sea lice can reduce the amenity values that outline the non-use value other than utility value. Amenity values include recreational fishing of wild stock, sceneries or biodiversity in this case.

The infection in salmon farms can be conveyed to the wild stock as well (Liu & Bjelland, 2014; Torrissen et al., 2013). Although it is still controversial in academia how close sea lice infection of farmed salmon are causally related to that of wild salmon, there is definitely a correlation between the two (Torrissen et al., 2013). The interesting difference in biological behavior of wild stock compared to farmed stock is the higher exposure of wild salmon to their carnivores. According to Grimnes and Jakobsen (1996), juvenile salmonids tend to leap and roll more than usual after the lice infection, which increases the probability to be recognized by the predators. This contributes to the decline of the wild stock.

Table 1: Impact of Sea Lice on Farmed Salmon

Cost effects	
Biological	• Reduced fish growth • Weakened immune system • Higher mortality • Contagious both on farm level and for wild stock
Economic	• Treatment costs • Increased finance, depreciation and insurance costs • Reduced feed conversion efficiency • Increased feed costs • Decreased market value • Negative publicity • Market distortion
Social	• Negative externality • Decreased amenity values

Nofima(2017) estimated the approximate costs triggered by sea lice as NOK 4 /kg in 2016, whereas Pareto Securities(2017) calculated that the cost in 2010 was NOK 1.5 /kg. This pin points the significance of the cost increase associated with salmon lice. Liu and Bjelland (2014) have highlighted the importance of treatment measures as well as management strategies based on the analysis of the economic effects of diseases on the farm level aquaculture sector measured through changes in productivity and profitability, among others. Our paper will mainly assess the current policy instrument and propose potential improvement or adjustment to optimize the management strategies for tackling the issue in an efficient and effective way (section 3.1. and 3.2.).

1.2.3. Treatments

The development of different treatment methods against sea lice have increased rapidly over the years to overcome the negative impacts lice have on salmon. We divide these into two groups, where the first one includes methods that remove lice from already infected salmon, while the second group includes preventive measures that keep the lice from attaching to a host (Mortensen & Skjelvareid, 2015)

Historically, chemical treatments (including antibiotics) have been the main method for the removal of sea lice. Other frequently used chemical agents include chitin synthesis inhibitors (Diflubenzuron), organophosphorus compounds (Azamethiphos), and hydrogen peroxide (Norwegian Veterinary Institute, 2016). These treatments are given to the salmon through feed (also referred as oral treatment) and so-called baths where the chemicals are released into the pen. Bath treatment in closed environments where the fish are pumped into an exterior facility (usually a well boat) in which the water contains the treatment is a frequently used method as well (Nilsen, Nielsen, Biering, & Bergheim, 2016). However, the use of chemical treatments in Norway has declined rapidly due to its several drawbacks. Firstly, the lice develop resistance against the medicine after a while, making the treatment less effective (Mortensen & Skjelvareid, 2015). Secondly, the chemicals can have a negative impact on the surrounding environment and on humans eating the treated fish (Burridge, Weis, Cabello, Pizarro, & Bostick, 2010). Lastly, the bathing process stresses fish, and can lead to slower growth and lower quality, and in some cases death of fish (Imsland et al., 2014). In response to the aforementioned problems, the development of new treatment methods has increased over the last decade in order to both overcome the lice problem and keep a high level of fish welfare. These methods are mainly mechanical and biological (Kvenseth & Solgaard, 2003; Mugaas Jensen, Skår Hosteland, & Soltveit, 2017; Sjøthun Røen, 2015)

The two main mechanical methods used in Norway as of 2017 are the so-called thermolicer, and flushing of salmon (Mugaas Jensen et al., 2017). In the thermolicer treatment, the salmon is pumped into an external facility (well boat) where the water is heated up to 30-34 degrees Celsius. The shock of higher water temperature makes the lice to let go of the salmon. This method is especially good against lice that have not fully attached to the salmon, and many praise it as a salmon-friendly treatment with relatively low levels of stress among the fish during the treatment. The downsides of this method are the pumping stage of the treatment that might increase the fish’s stress level, and the risk of surviving lice finding a new host when the water from the well boat is pumped back into the ocean. There is also an alternative method using freshwater. However, scientists have recently found that the lice can develop resistance to the increasing water temperature both in seawater and in freshwater (PwC, 2017).

Flushing of salmon is more effective against lice that have completely attached to the host (Mugaas Jensen et al., 2017). The treatment process is similar to the thermolicer (and most other mechanical treatments) in that the farmer pumps the fish into a well boat. The fish travel through pipes while water flushes them for up to ten seconds. The lice let go off the salmon, but the same problem of reattachments of surviving lice is present in this method. Even though the technology aims to improve the fish welfare, the stress level of the salmon is still a drawback of using this method.

The third and last common treatment method in the lice-removal group is biological method, where farmers release cleaner fish into the pens (Imsland et al., 2014; Kvenseth & Solgaard, 2003; Mortensen & Skjelvareid, 2015). This method has grown steadily since its introduction in the late 1980s (Bjordal, 1991; PwC, 2017; Skiftesvik, Bjelland, Durif, Johansen, & Browman, 2013). Cleaner fish feed on lice that have attached to the salmon in addition to lice that are mobile in the pen. The two main species of cleaner fish are wrasse and lumpfish. Today, specific cleaner fish farmers and big aquaculture companies farm cleaner fish for the sole use of combatting the lice problem (Marine Harvest, 2017b; Powell et al., 2017). As chemical treatments are less used, and mechanical treatments are costly and can lead to stressed fish, cleaner fish have become a sustainable and salmon-friendly method to deal with the lice problem. Even though cleaner fish have many advantages over non-biological treatments, they still have some drawbacks in terms of them feeding on the pen net or pellets originally meant for salmon and feeding on the eyes of the salmon, eventually killing it (Imsland et al., 2014; Kvenseth & Solgaard, 2003).

The second group of treatment methods is prevention of lice attaching to the salmon host. The by-far most popular method is using a so-called lice skirt (Frank, Gansel, Lien, & Birkevold, 2015; Mortensen & Skjelvareid, 2015; Stien et al., 2012). It has been proven that sea lice are mainly found close to the water surface, from 0 to 4 meters (Hevrøy, Boxaspen, Oppedal, Taranger, & Holm, 2003). As a response to this, some farmers will attach a “skirt” to the pen, which prevents the lice from entering the pen. These skirts are usually 5-10 meters deep, and have had a large impact on the fight against salmon lice (Stien et al., 2012). The drawback of salmon skirts is the affected flow of water due to the blocked off upper part of the pen. This results in lower oxygen levels and water quality within the blocked area (Næs, Heuch, & Mathisen, 2012).

There are other existing prevention methods, but these are not as common as the ones described above. These methods include a “snorkel” pen that prevents the lice from entering the pen by blocking it off completely, forcing the fish to stay deep with a snorkel providing oxygen (Mortensen & Skjelvareid, 2015; Stien et al., 2012), and biological methods including breeding of lice-resistant salmon (Sjøthun Røen, 2015). Many believe that the future of salmon farming will be done in closed or land-based facilities, completely preventing the lice from attaching to the salmon (Mortensen & Skjelvareid, 2015; PwC, 2017).

1.2.4. Literature Review

As the lice problem has increased over the last decades, several studies have tried to quantify the cost of lice, but most of them have estimated the direct costs. The number of papers concerning the indirect costs is limited, but Abolofia et al. from 2017 is able to present numbers based on the loss of biomass due to lice. The research uses farm-level data of Norwegian farms from 2005 to 2011 and they state in the paper that their study is the first to use a rich dataset to present an empirical study on the indirect cost of lice in Norway. In addition, they divide the country into three different regions, where they find that there exist inter-regional differences of lice impact. Specifically, they find that costs related to lice amount from 3.62 per cent to 16.55 per cent of revenues, depending on farm location. This amount to NOK 1.08/kg and 4.80/kg respectively (See how these numbers have been adjusted to 2016 NOK-values in section 1.1). Their numbers include direct costs of NOK 225,000 per treatment, thus it is hard to predict the exact indirect cost amounts. The methodology of this paper is in many ways similar to the one of this thesis, thus it will serve as a benchmark of our results and a source of comparison.

In addition to the paper on indirect cost of sea lice, several papers and reports have been written, estimating the direct cost of lice. It is important to mention that many reports state that the direct costs related to lice have increased over the last decade, thus it is natural that the following numbers vary, as most of them are not from the same year. A paper by Liu and Bjelland (2014) suggests that the direct costs of lice amount to around NOK 3.30/kg in 2014, which they argue is a fourfold increase from 2011 when Marine Harvest stated the cost was NOK 0.79/kg. This paper does not include an analysis of the different regions in Norway, but when comparing the cost to the average cost from Abolofia et al., it seems that Liu and Bjelland have a slightly higher number. Reports by Nofima (2017) and PwC (2017) both argue that the direct costs of treatments and preventions amount to around NOK 4/kg in 2016.

Furthermore, there are several papers addressing the future scenarios in aquaculture through different approaches. World Bank Group (2013) provided a broader perspective with general global dynamics of the aquaculture industry and fisheries. The scenarios illustrate the baseline together with additional variations. Sintef (2012), which was co-written by experts from different sectors, focused on Norway and defined the relevant global and domestic trends including urbanization, energy demand, and the Norwegian seafood cluster. Whereas PwC (2017) has divided the scenarios into three; optimistic, base and pessimistic by the different levels of production volume. The paper infers that the success of newly developed technologies, cost efficiencies, government initiatives and development of current and new challenges are one of the most significant factors for future scenarios assuming that the level of sea lice will decrease. Finne (2017) examined the future scenarios through the SRI approach proposed by Stanford Research Institute, which is the closest path of methodology we apply in our thesis. Four different scenarios imply the production level in 2050 will vary depending on distinctive environmental factors, and corresponding action plans are suggested as long-term strategies for firms. However, Finne (2017) illustrates the general landscape of the industry in 2050 and argues the necessity of the resolution for sea lice problem, and the paper does not state the specific aspects regarding the sea lice problem. Our paper's focus is on how the government can shape the industry.

2. Methodology

We have divided the methodology chapter into two sections where the first section presents the quantitative analysis of indirect and direct cost of sea lice, while the second section does a qualitative section analyzing the long-term implications for the stakeholders regarding the incurred costs of sea lice. In the first part of the qualitative analysis, we discuss the model we use in the analysis of the indirect cost of salmon lice, and the factors included in this model. We then move on to a description of the datasets we use in the analysis, and how we clean and process these datasets to prepare them for the analysis. The last part consists of the analysis of the indirect costs and the estimation of direct costs and the sum of the two. On top of that, the second section first introduces the frameworks and tools used for the qualitative analysis of the salmon industry in the long run. The PESTEL analysis, critical drivers, and the scenario planning analysis for the stakeholders in salmon aquaculture follow, which connect to recommendations in section 3.

2.1. Quantitative section

2.1.1. Model

The goal of this analysis is to measure both the direct and indirect costs related to sea lice. Direct costs are those costs incurred from lice treatments while indirect costs are revenues lost from reduced growth of biomass due to sea lice. The direct costs are relatively easy to observe; thus, we use a report by Nofima from 2017 using 2016 data to estimate the direct costs. This estimation takes place later after the indirect cost analysis. It is harder to measure the indirect cost because this depends on biological factors, which can be hard to observe. We therefore use a biomass growth model that captures variables that we believe have an effect on biomass growth. We also control for the existing regional differences proven by Jansen et al. and discussed later (2012). We base our model on a similar model made by Abolfilia et al. (2017) whose data is from January 2005 to December 2011. Thus, it is natural to use this paper as a benchmark when presenting the results of the analysis. The model we are using is this biological growth model:

$$r_{it} = \frac{(Biomass_{it} - AB_{it}) - Biomass_{it-1}}{Biomass_{it-1}}$$

where r_{it} is the monthly growth rate of biomass at time *t* in farm *i*. AB stands for ancillary biomass and is calculated as followed: AB_{it} = ($stockings_{it}$ - $harvest_{it}$ - $escapes_{it}$ - $mortalities_{it}$), where $stockings_{it}$ is the release of fish into the farm *i* during time *t*. In order to measure the effect lice have on the biological growth of biomass we express r_{it} as a nonlinear function of time dependent explanatory variables:

$$\ln(1 + r_{it}) = \ln(\frac{Biomass_{it} - AB_{it}}{Biomass_{it-1}})$$

In the following parts, we discuss the data and the preparation process before we return to the model and the analysis.

2.1.2. Data

Norway has a strict set of regulations that salmon farmers have to follow. Among other things, the farmers are required to submit weekly and monthly statistics on the standing biomass in each pen and average lice numbers to the Norwegian Directorate of Fisheries (NDF) and the Norwegian Food Safety Authority (NFSA). These statistics include variables that we believe to have an effect on biomass growth based on the research by Pike and Wadsworth (1999). These variables are standing biomass levels, average number of sea lice per fish, seawater temperatures, and ongoing treatment methods. Because all the data should be reported by the beginning of the next month (or beginning of next week in the case of the lice count and sea temperature), it allows us to conduct an analysis with relatively new data, and thus provide an updated status of the cost of sea lice in Norway. We use two main datasets in the analysis: one for biomass and one for lice. The biomass dataset is from the Norwegian Directorate of Fisheries and contains biomass data from all farms and pens in Norway. This allows us to conduct an analysis where we use end-of-month data from January 2013 to December 2016. The dataset also includes the farmed species in each pen. The two species that we use in the analysis are Atlantic salmon and rainbow trout.

The lice dataset is from the Norwegian Food Safety Authority and the data is weekly as farmers are required to report lice levels every week. The dataset includes the average number of female, mobile and attached lice per fish in the farm. In addition, it includes the longitudes and latitudes of the farms, and the water temperature in the sea at the time of the count. This allows us to include factors such as temperature and geographical location in our analysis. The NFSA also provides data on the ongoing treatment processes in each farm. This data includes what kind of treatment is in process, for example cleaner fish or chemical. The name of the chemicals used or the number of one specific cleaner fish are reported as well, and this allows us to conduct an analysis of the direct cost related to sea lice later.

The advantages of the data are that both biomass and lice datasets include the farm-specific location number, which makes it easy to merge the two sets together. As we have different farms over time, the data is panel data, which allows us to run a fixed effects regression that will control for fixed farm-specific variables.

The data requires processing. Firstly, the biomass data is monthly, while the lice data is weekly. Secondly, farmers must report the biomass data at pen level, while the lice data is for the farm as a whole. We address and solve these issues in the following section.

2.1.3. Data preparation process

Because there are two different datasets, we follow several steps in order to prepare the data to be fully applicable for the analysis. We clean, process and analyze the data in the Stata software (See Appendix II for the main codes for the analysis). The only exceptions are the manually entering of stockings and escapes, and some manual calculations of the growth, which are done in Microsoft Excel.

As already mentioned, the biomass data includes every pen of a farm, while the lice data only reports the lice count for the whole farm. This limits our thesis to a farm-level analysis, which may not be as accurate as a pen-level analysis. Consequently, we add all the pens together resulting in every farm having only one observation each for every month. The limitation of this is that there might be a loss or miscalculations of changes that have occurred on pen level, but are too small to affect the "trend" of the farm as a whole. An example would be if harvesting only takes place in one pen, but the growth of the rest of the farm is so large that the net farm biomass is still larger than the previous month. Thanks to the manual entrance of the stocking values, we are able to solve this problem to a certain extent, but there may still be observations that are biased. In addition, some farmers did not report the correct amount of biomass, and the most frequent issue is that the farmer would forget to add all the pens to the report one month. An example would be that the farmer reports biomass data for ten pens in January, one pen in February and ten pens again in March. In these cases, the growth of the one pen from February represent the growth of all the other pens.

Stocking of fish into the pens normally occurs either in the spring or in the fall, but this does not necessarily happen in the same month in all the pens of the farm. As the biomass data is for each pen of the farm, it is possible to enter the stockings manually into the dataset assuming that the introduction of new fish into a pen that used to be empty is a release of new fish. It seems from the dataset that in some farms, farmers will release fish from one pen to another when the biomass has grown to a certain level. An example of this would be one farm that has two pens with registered biomass in month t and four pens of registered biomass in $t+1$. The decrease of the biomass in the two original pens reasonably amounts to the increase of biomass in the two added pens. “Reasonably” means that the amounts are not exactly equal, but when taking mortality and slightly different growth rates in each pen into consideration, it is reasonable to say that the additional biomass comes from the original pens. That is, when there is stocking of fish in a pen that used to be empty, at the same time as the biomass in other pens of the farms have gone down by a reasonably similar amount, the assumption is that there has been no release of new fish into the farm.

In order to calculate the revenues for each farm later, a variable for harvest is necessary. Thus, when the standing biomass is decreasing from one month to another, it is natural to assume that there has been harvesting at the farm (except if there have been fish escapes that explains the biomass reductions. This is true for only two observations in the dataset). When calculating the growth in farms where harvesting have been taken place over the month, the growth rate is significantly deflated in almost all cases. Consequently, we find the mean growth rate of each month, and then multiply the reduction in biomass by the corresponding average growth rate, thus assuming that the harvesting of the fish takes place at the end of the month. This number would still not be perfect as the mean growth for each month would already be affected by the deflated growth levels of the farms that were harvesting, but there is no significant change in the results when redoing the process several times to pinpoint the real growth as much as possible.

The regulations require all farmers to report any fish escapes from the farm to the NFSA. However, some farmers fail to do this (Abolfilia et al., 2017). From the data, it is easy to see that many farmers are estimating the best guess when fish have escaped as the escaped biomass is often stated in whole 1000s. For the last variable of the AB, mortalities, there are no exact numbers but the results has basis on a report by SalMar from 2017 saying that on average 1 per cent of the standing biomass at the beginning of the month die during the month (SalMar, 2017).

In order to control for fish size, a weight variable is necessary. The weight of every fish is 250 grams when released. This has basis in reports by Marine Harvest (2017b) and SalMar (2017). The fish grow at the monthly rate, which is calculated next.

The next step of the pre-processing is to finalize the biomass dataset is to generate the monthly growth rate for each farm using the growth model presented earlier, and to take the natural logarithm of the growth rate to find the dependent variable of the analysis. Next, the preparation of the lice data follow. As already mentioned the lice data is weekly and have to be transformed into months. If a week starts at the end of a month and ends in the next, this week will be part of the month it started in. Taking the mean lice count of the whole month (four or five weeks) reduces the effect of this problem. The weekly lice count is the mean of the mean of ten fish from 50 per cent of the pens (Abolfilia et al. 2017). Another advantage of taking the mean is that some farms fail to report the lice levels, and by choosing only the last week of month, the risk of not having any data for that month would be present. Consequently, by taking the mean of all the counts of the month, the representation of the actual lice level over the month is better. The dataset includes three lice variables: adult female lice, attached lice, and mobile lice. To run the regression, only one lice variable is necessary, thus, the sum of female and mobile lice make up the variable "total mobile lice." Earlier research shows that attached lice do not make as much damage as mobile lice, thus this variable is not part the regression. (Sea Lice Research Centre, n.d.). When testing the significance of the variables, attached lice is the only variable, which is not statistically significant.

The lice dataset also includes the seawater temperature for each week, and as with the lice count, the monthly average of the weekly temperatures is a better representation of the temperature for the whole month. Additionally, the dataset includes the longitudes and latitudes for each farm, which enables the division of farms into geographical regions. This division follows the research of Jansen et al. (2012), which groups the country into three regions based on unique traits special for each region. Examples of these traits are farm density, farm size, seawater temperature, and lice level. The names of the three regions are South, Central and North, and the Central region consists of farms between latitude 67 hours and 62 hours and 35 minutes. Dummy variables for the three regions will allow the comparison of regional differences later.

The last step is to create a variable called "Months at sea" which covers the number of months the fish have been in the farm. Ultimately, this is the time variable in the panel data regression, and enables the result to be based on multiple cycles over the four years of data. The monthly growth rate should differ over the production cycle, thus it is important to include this variable in the regression. In addition, this variable lets us calculate the monthly biomass lost due to sea lice in the prediction that we present later. The last month at sea for cycles that started in 2012, a year not included in the data, is assumed as month number 17, as this is the median last month of all the cycles in the dataset. This can create a bias as fish released in the fall normally have a shorter cycle than fish released in the spring: 16 and 20 on average respectively (Abolfilia et al., 2017).

Table 2: Summary Statistics

Variable	Observations	Mean	Std. Dev	P5*	P95*
Months at sea	24433	9.19	5.53	1	18
Water temperature (Celsius)	24433	9.19	3.58	3.79	15.3
Standing fish biomass (kg)	24433	1346248	1174849	100217.6	3614570
Average fish weight (kg)	24433	2.31	1.73	0.25	5.52
Number of fish mortalities (kg)	24432	13106.02	24011.37	620.02	35964.83
Number of fish escapes (kg)	95	17523.12	41539.91	1.50	124687.70
Harvested fish biomass (kg)	6456	721377	722383.10	16941.51	1972757
Adult female lice (avg/fish)	24394	0.18	0.36	0	0.65
Adult other mobile lice (avg/fish)	24394	0.80	1.37	0	3.5
Total adult mobile lice (avg/fish)[a]	24394	0.98	1.61	0	3.78
Northern region (dummy)	24433	0.27	0.44	0	1
Central region (dummy)	24433	0.29	0.45	0	1
Southern region (dummy)	24433	0.44	0.50	0	1
Treatment[b]	24433	0.49	0.48	0	2

* P5 and P95 are the 5th and 95th percentiles of the data

[a] adult female lice plus other adult mobile lice

[b] number of treatments underwent at the location that month

Source: Norwegian Directorate of Fisheries; Norwegian Food Safety Authority

2.1.4. Analysis

2.1.4.1. Indirect cost

The goal of the analysis is to see the effect sea lice have on the monthly growth of standing biomass in each farm over the time of the growth cycle. As the data is panel data, the model is run using a fixed effects regression, which controls for fixed farm-specific effects. Thus, the regression model is as follows:

$$lngrowth_{it} = \beta_0 + \beta_1 time \; + \; \beta_2 months\ at\ sea_{it} + \; \beta_3 biomass_{it-1} + \beta_4 weight_{it-1} \\ + \beta_5 total\ lice_{it-1} + \; \beta_6 seatemp_{it-1} + \; u_i + \; v_{it}$$

where v_{it} is the unobservable error and u_i is the fixed farmed-specific variables. In this analysis, these variables are limited to the geographical regions mentioned above. Months at sea is the time variable in the panel data regression, and it measures the number of months since the initial stocking of fish in the farm. The total lice variable is the most important explanatory variable, as the goal is to try and are find its effect on growth. The variables that influence growth will affect it over time, thus all the variables except the time variables include a one-period lag. The time variable controls for year fixed effects. In addition, the interaction terms control for relationships between explanatory variables in the regression model. Table 3 presents the regression results and includes the interaction terms. A panel data regression includes the option to run it with random effects, and one should run this option as a separate regression. The model for this regression is very similar to the fixed effects one, but the dummy variables for the geographical regions have to be included. To test if the fixed effects regression is the analysis to use, the results from both options are stored, which enables the conduction of a Hausman test. The results from the Hausman test show that $p<0.01$, thus we reject the null hypothesis that random effects are present and conclude that the fixed effects regression is the one to use. The results from the fixed effects regression follow in the table below.

Table 3: Fixed Effects Regression Results

Variable	Coefficient	Standard Error	t-value	p-value	95% confidence interval	
Months at sea$_t$	-0.039908	0.0009954	-40.17	0.000	-0.041942	-0.0380397
Biomass$_{t-1}$	-3.65e-08	1.20e-09	-30.43	0.000	-3.88e-08	-3.41e-08
Average fish weight$_{t-1}$	0.0784879	0.0030023	26.14	0.000	0.0726031	0.0843727
Average total lice$_{t-1}$	-0.0138111	0.0020051	-6.89	0.000	-0.017741	-0.0098809
(Average total lice$_{t-1}$)^2	0.0009216	0.0000819	11.25	0.000	0.0007609	0.0010822
Average total lice$_{t-1}$ × average fish weight$_{t-1}$	0.0014548	0.0003423	4.25	0.000	0.007838	0.0021258
Average total lice$_{t-1}$ × biomass$_{t-1}$	3.33e-09	4.53e-10	7.36	0.000	2.44e-09	4.22e-09
Average total lice$_{t-1}$ × average sea temperature$_{t-1}$	-0.0017953	0.0001351	-13.29	0.000	-0.002060	-0.0015305
Average total lice$_{t-1}$ × treatment$_t$[a]	0.0046661	0.0008338	5.6	0.000	0.0030318	0.0063004
Average sea temperature$_{t-1}$	0.0236008	0.0011091	21.28	0.000	0.021427	0.0257747
(Average sea temperature$_{t-1}$)^2	-0.0004836	0.0000539	-8.98	0.000	-0.000589	-0.000378
Farm Fixed Effects	F = 3.31**					
R^2	0.5431					

[a] We include treatments as an interaction term to average total lice because we expect the number of lice to go down after a delouse treatment has been conducted.

** p-value < 0.01

Year fixed effects are controlled for, but not included in the regression table.

The regression results show that all variables are statistically significant at the 1 per cent level, and that the overall R^2 is 0.543. This suggests that the model's fit is reasonably good, but that there are still factors that we have not accounted for. These factors may include feed use, number of fish and unobservable farm-specific factors that the fixed effects regression does not capture. More importantly, the results show that there is a significant negative relationship between the average number of lice per fish and the growth rate. Additionally, the interaction terms show that the effect lice have on the growth diminishes as the number of lice and fish weight increase or if there is a delousing treatment at the location. Similarly, the effect intensifies when temperatures are higher. Thus, we conclude that the fish is most vulnerable to lice when it is small and temperatures are high, as well when no or few lice have infested it and no treatment has been conducted.

By looking at the marginal effects of one additional lice, it is possible to compare how the three regions differ in terms of growth reduction due to sea lice. Table 4 lists the results below.

Table 4: Marginal Effects at Means of Sea Lice

Region	Marginal effects at means
North	-1.754% **
Central	-1.829% **
South	-2.093% **

** p-value<0.01

From table 4, there exist heterogeneity between regions as the increase of one lice from 0.49 (regional average lice per fish) in the North region will decrease growth the next month by 1.754 per cent. On the other hand, an increase of one lice from 1.33 in the South region will decrease the growth by 2.093 per cent the next month. These numbers are slightly lower than in the paper by Abolfilia et al. (2017). Their data runs from 2005 to 2011, while ours covers the months from January 2013 to December 2016. The means of the covariates might have changed over the years, and thus may give a different result. The differences in the means of the covariates are some of the reasons why there exist heterogeneity between the regions, and it is reasonable to believe that these contribute to differences over time as well.

In order to calculate the growth lost by sea lice, we create a dataset where total lice and treatments are set to zero and the rest of the covariates are set to their respective region and month-at-sea averages. In other words, we try to see the how much larger the monthly biomass growth is ceteris paribus with no lice and thus no delousing treatments. After running the regression analysis, Stata can predict the no-lice growth rate, r_{it}^{nolice} , in the no-lice dataset. When predicting using a logarithmic model as in this case, the well-known log-transformational bias arises. There are different ways to deal with this bias (Cameron & Trivedi, 2010). When choosing which estimator to choose, we choose to look at the differences in means and standard deviations between the estimators and the original growth rate, r_{it}. This examination predicts the growth in the lice dataset and then transforms the values using different estimators. The estimator that was the most similar to r_{it} was Duan's estimator (1983) and the growth rate is transformed to r_{Duan}^{nolice}. The transformed growth rate, r_{Duan}^{nolice}, enables the calculation of the biomass growth when there is no lice and r_{it}^{lice} when there is lice:

$$\hat{b}_{it}^{lice} = r_{it}^{lice} * biomass_{t-1}$$

$$\hat{b}_{it}^{nolice} = r_{Duan}^{nolice} * biomass_{t-1}$$

$$\Delta\hat{b}_{it} = \hat{b}_{it}^{nolice} - \hat{b}_{it}^{lice}$$

Where $\Delta\hat{b}_{it}$ represents the average biomass lost each month for each farm. Table 5 shows the monthly biomass lost for a typical production cycle for farms in the three different regions respectively. The two last columns show the loss per kilo of harvested biomass and the percentage of revenue lost after one production cycle. That is, table 5 shows the amount of potential revenue lost due to sea lice that farmers can expect over the duration of a typical production cycle.

Table 5: Summary of Biomass and Money Lost due to Sea Lice

Region	$\Delta\hat{b}_{it}$	Money lost per month	Money lost per cycle	Total revenues	Loss per kilo	% of revenue lost
North	6,165	kr 285,324	kr 4,850,502	kr 107,445,962	kr 2.09	4.51%
Central	12,033	kr 556,883	kr 9,467,012	kr 119,343,023	kr 3.67	7.93%
South	17,266	kr 799,064	kr 13,584,088	kr 84,414,396	kr 7.45	16.09%

NOK amounts are based on the average weekly salmon price of NOK 48.28/kg between January 1, 2013 and December 31, 2016. One cycle at sea lasts 17 months on average. Total revenues are calculated using total average harvest per location multiplied with the weekly average salmon price.

From table 5, there are large differences from region to region where farmers can expect to lose 4.51 per cent, 7.93 per cent, and 16.09 per cent of the biomass in the North, Central and South region respectively. These numbers are significant as they show that farmers in the South can expect to lose almost four times more biomass due to lice compared to a farmer in the North during a normal production cycle. It is important to note the fact that less fish are harvested, which means that less fish reach the market, thus the supply curve shifts to the left. Because of this, the equilibrium price increases and reduces the impact of lost biomass. How much the impact decreases is hard to measure and requires further research, and this thesis will not cover these issues.

2.1.4.2. Direct and total costs

In order to measure the total cost of sea lice, the direct costs are added to the indirect costs. The direct costs are easier to observe, and we will therefore use a report by Nofima from 2017 using 2016 data, which quantifies the per-kilo costs for different delousing treatments. This means that the report presents the direct costs in 2016 NOK-values even though only a quarter of our data is from that year. Since this thesis aims to quantify the total cost of lice for farmers today, we do not consider it a problem not to discount the costs for years earlier than 2016.

The lice dataset from the NFSA contains information whether or not there is a treatment process on a farm for each month. It also contains information on what treatment method is in process, and which chemicals or cleaner fish are being used. If there is an ongoing mechanical treatment, the type of treatment is not stated, thus the weighted average of the costs of the different mechanical types is representative. The weights have basis on a report by PwC (2017). See appendix III for the different costs of per-kilo treated. Table 6 shows regional averages of cost-per-kilo of direct costs and the total cost of salmon lice:

Table 6: Summary of Costs for Each Region

Region	Cleaner fish	Mechanical	Chemical	Total direct cost	**Total cost/kg**	**Total cost % of revenue**
North	kr 0.54	kr 0.73	kr 0.29	kr 1.57	**kr 3.66**	**7.52%**
Central	kr 0.58	kr 0.81	kr 0.30	kr 1.70	**kr 5.37**	**11.05%**
South	kr 0.76	kr 0.69	kr 0.27	kr 1.72	**kr 9.17**	**18.86%**

Table 6 shows the costs related to treatment methods per kilo of harvest biomass. It is important to note that direct costs per kg is based on total biomass harvested, not just for the farmers who conducted delousing treatments. Obviously, the cost per kg would be significantly higher if only those farmers were included. The cost per kg of total biomass harvested gives a better representation of the expected cost of sea lice the farmers will incur during a normal production cycle. It is also important to mention that the direct costs presented do not include costs of preventive methods as mentioned in chapter 1.2.3. as farmers are not required to report the use of these methods. Consequently, the direct costs above are slightly understated as Nofima estimates the cost of lice skirts to amount to NOK 0.08/kg harvested (2017).

Table 6 shows that the costs vary a lot from region to region and it is clear that lice have a big impact on the revenues of the salmon farms, where farmers in the South can expect to incur NOK 9.17/kg of total costs related to sea lice in a typical production cycle. This corresponds to a total cost of 18.86 per cent of revenues. The same numbers for the Central and North regions are NOK 5.37/kg (11.05 per cent) and NOK 3.66/kg (7.52 per cent) respectively. Even though there is a big spread between the different regions, the numbers are following the same trend as in the paper by Abolfilia et al. (2017). In that study, the authors find that the costs in the North are NOK 1.07/kg (3.02 per cent); NOK 3.29/kg (9.01 per cent) in the Central; and NOK 4.80/kg (13.10 per cent) in the South. In their study, they have used a direct cost of NOK 225,000 for all delousing treatments, which is definitely less than the average cost per treatment in our dataset of NOK 993,000. Their data end in December 2011, and it is reasonable that they have used treatment costs from 2011, as direct treatment costs have risen substantially over the years (PwC, 2017; Nofima, 2017). How they calculated the cost amount is not stated in the article, thus it is hard to compare it fully as the numbers provided by Nofima and used in our analysis include many different factors that affect the total cost (rent of well boat, working hours etc.). If we look at the numbers from the indirect cost analysis, we still see that the costs related to the reduction in biomass growth have increased in two of the regions. Our (their) percentage values of indirect cost per kilo for the different regions are 4.51 per cent (3.02 per cent), 7.93 per cent (9.01 per cent), and 16.09 per cent (13.10 per cent) for North, Central and South regions respectively. This tells us that even though treatment costs are increasing, farmers in the South and the North still lose a higher share of potential revenue to the reduction of growth due to sea lice compared to Central. Again, the numbers in parentheses include a direct cost of NOK 225,000, thus it is hard to estimate if the indirect cost in the Central region has increased or not. The reasons why we do not see an increase in the cost as we do in the two other regions may include region-specific biological factors, which can be both observable and unobservable.

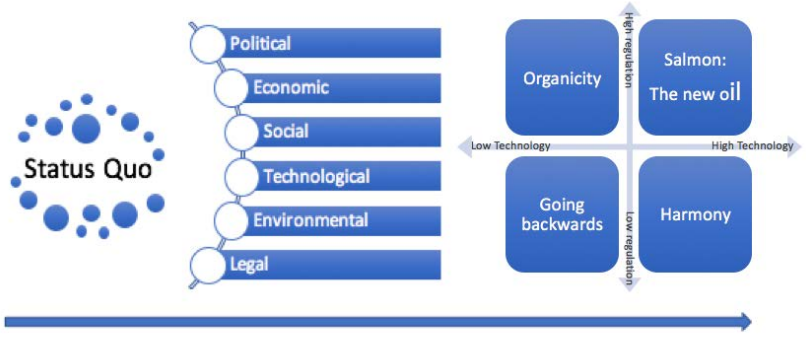
2.2. Qualitative section

2.2.1. Important concepts and frameworks

The previous section shows that the cost effects of sea lice on salmon farming are severe, and increasing on average throughout the country. The problem is not restricted to specific farms in certain regions but rather cross-regional. Thus, in addition to the cost analysis, it is also imperative to project the holistic future landscape of the salmon farming industry in regards to sea lice. Since the lice problem is one of the most critical challenges the industry is facing, this section's analysis is able to benefit the stakeholders in salmon aquaculture to prepare themselves appropriately. The qualitative analysis can address some of the potential problems or challenges in advance, which helps the stakeholders to better prepare for the uncertain future. At the same time, it can also assist the stakeholders with identifying the opportunities and setting up corresponding strategies.

The government has already announced the goal of reaching five million tons of farmed salmon production by 2050. However, only one third of the leaders in the industry believe that this target is achievable (PwC, 2017). Is the goal realistic? It is not very likely if the negative impact of lice remains at the current level or even bigger without any appropriate actions. Therefore, this section's qualitative analysis identifies the potential scenarios and the following suggestions for the government to reach the stated goal. To tackle the sea lice problem is one of the most important components since level of lice is an increasing critical cost factor, which hinders the productivity of salmon farms. Figure 3 introduces the structure of methodologies applied in this section is as follows:

Figure 3: Process of Qualitative Analysis



To begin with, the status quo of the industry, and the critical trends and signals are examined through the PESTEL framework in order to illustrate the most relevant and potential future scenarios. The trends identified by the PESTEL analysis signal certain specifics of each scenario. Next, the most relevant drivers for shaping the future of the salmon farming industry are selected based on each factor's impact and uncertainty. The critical drivers are assessed to have high impact and be of high uncertainty for the future.

Firstly, the PESTEL framework is used to identify the external macroeconomic factors that will have an impact on the salmon aquaculture sector in Norway. The PESTEL framework considers political, economic, social, technological, environmental and legal factors regarding sea lice and the Norwegian salmon aquaculture sector respectively. Each factor highlights different aspects of the industry (Newton & Bristoll, 2013).

Political factors cover different sets of regulations ranging from taxation to health and safety requirements. The factors can be either geo-political or national, such as changes in local governmental development strategy and policy or international relations. Economic factors include assessing potential changes to the economy such as exchange rates, and labor costs, among others. Social trends describe the characteristics of the society and its members. The important value of the society and demographic patterns, and historical issues are often included. Technological factors measure the rate of change and innovation and how these are implemented into the industry. Environmental factors can be ecological consequences, and social implications for these consequences. Lastly, laws and regulations are common legal factors that have an impact on the industry and its operations. Even though it is difficult to cover all aspects that have impacts on the industry due to restrained time and resources, the aim of this framework is simply to identify as many factors as possible (Newton & Bristoll, 2013). Some of the trends can belong to more than one factor. For example, trade related policy can be both political and legal. As long as a critical trend is identified through the framework, it is of a minor importance which category it belongs to. Table 7 summarizes the different factors of the framework.

Table 7: Different Factors of the PESTEL Framework

Factors	
Political	Regulation, international relation, bureaucracy and corruption
Economic	Macroeconomic conditions, microeconomic conditions, market forces, impacts of global economy and development
Social	Social factors, demographic patterns
Technological	Infrastructure, future directions
Environmental	Physical environment, natural resources
Legal	Compliance, regulatory bodies

The trends from the PESTEL analysis are mapped out in an impact/uncertainty matrix. Those trends scoring high uncertainty and high impact with low correlation between themselves are selected as the axis for future scenarios. Based on the two axis, four separate scenarios illustrate the future of the salmon farming industry in Norway to manage risk and develop robust strategic plans in the face of the future (Krueger, Casey, Donner, Kirsch, & Maack, 2001).

Scenario planning is an impactful tool for anticipating and managing changes on an industry level or environmental level. This qualitative approach has its merits of developing flexible and consistent scenarios in the long run. Some of the highlights are that decision makers can capture the hidden aspects through widened range of probable future outcomes with scenario planning, thus encouraging them to consider the developments they would not otherwise. This ultimately can assist the organizations to adapt and prepare for the future by enhancing their abilities to cope with uncertainties and changes (Amer, Daim, & Jetter, 2013; Schoemaker, 1995). However, one of the demerits of the approach is that it is highly dependent on the analysis conductors. This implies in terms of both the skills of the people executing the analysis and the quality of the input data used (Amer et al., 2013; Huss & Honton, 1987). To add, the process is time consuming, and it can vary a lot depending on the individuals. However, being aware of the drawbacks and thus reflective during the analysis process can prevent from falling into tricky traps (Molitor, 2009; Peterson, Cumming, & Carpenter, 2003). In the following, we present the significant factors for the main strategic concerns. Based on these, illustration of potential future scenarios, and discuss relevant implications and following action plans.

2.2.2. The PESTEL Analysis

The megatrends which indicate a positive future for salmon aquaculture industry. The increasing world population corresponds with the rise in demand for nutritious food. The health-conscious consumers are more aware of where their food sources come from and how they are processed. Concerns related to environment and sustainability in the aquaculture sector is crucial as well. For a more specific detailed analysis of the status quo, PESTEL analysis is conducted in this section. The factors are also presented throughout the whole paper. The key factors are summarized in brief in the following.

Political Factor

Norway is renowned as a resource rich country, being the twelfth largest crude oil exporter with its sovereign fund valued at USD 910 billion, which is the largest in the world. Despite its resource abundance, the government tries to avoid the resource curse that might hinder the development of the national economy. The government has different approaches and one is to put strong emphasis on utilizing the renewable resources, such as marine resources and aquaculture. Aquaculture products account for one of the biggest export sector of the country, and Atlantic salmon and rainbow trout represent 99.6 per cent of the aquaculture products (Euromonitor International, 2018; Statistics Norway, 2017a; World Integrated Trade Solution, n.d.)

The government plays a big role in Norway, with one third of the nation employed in the public sector, which accounts for nearly sixty per cent of GDP (Euromonitor International, 2018). The general political system of the country can be characterized as transparent but bureaucratic. According to Transparency International, Norway is ranked as the third most transparent countries together with Finland and Switzerland (Transparency International, 2018). However, World Economic Forum mentioned in its annual global competitiveness report that the main factors hindering the business to foster in Norway are as follow: Tax rates, insufficient capacity to innovate, restrictive labor regulations, access to financing and inefficient government bureaucracy (World Economic Forum, 2017).

The Ministry of Trade, Industries, and Fisheries has set an ambitious goal of reaching five million tons of production in 2050. In addition, around 95 per cent salmon produced in Norway is exported. Therefore, Oslo reached a deal with the EU in 2015 that provides Norway with increased access to European fish markets. This can provide a significant boost to the country's important fishing industry (Euromonitor International, 2018). Moreover, the government has been negotiating a Free Trade Agreement with China. The most recent negotiation round was held in Oslo in May 2018, which has shown positive progress. International trade dynamics can play a critical role since there might be a chance of potential trade barrier if Norway keeps dominating the salmon production and act as swing producer.

Economic Factor

Fisheries and aquaculture are some of the most valuable industries in Norway together with oil and gas, tourism and shipping. The unique characteristics of the aquaculture industry are important economic factors. The sector can be defined as consolidated industry with big international players including Marine Harvest, Lerøy Seafood, SalMar, and Grieg Seafood. Some are arguing the possibility of mergers and acquisitions of small and medium sized farmers and further consolidation of the market (PwC, 2017). Moreover, the industry is considered to have lower responsiveness to the changes in market because of the natural high production cycle, which is approximately two to three years.

Market price fluctuates heavily. Even though Norway had slowed down its production, the country still saw a 29 per cent increase in total export value and all-time high margins (EY, 2018; Thorstad et al., 2008). One possible explanation can be from the increased exchange rate of USD/NOK. Norwegian salmon products have high reputation and a strong global market share already, future demand has positive outlook with growing demand. With increasing lice costs, fluctuating price level can lead to periods where farmers and other operators in the aquaculture industry may experience negative operational margins especially when the price is low. The operational cost amounts to around NOK 36/kg as of 2016 (PwC, 2017; Nofima, 2017), and increasing costs related to feed and lice may reduce the operators capacity to invest in new technology that can overcome the lice problem.

According to Asche, Guttormsen, and Nielsen (2013), the industry is mature that overall growth in the industry and production increase between 1996 to 2008 were mainly from higher demand and increased input factor including feed and farming sites among others, rather than increased productivity factor. Farming sites with highest yields are already taken, and the farmers face competition with other players in the society including recreational users as well as other farmers.

Social Factor

The demographics of Norway shows an aging population with high purchasing power, with GDP per capita of USD 47,000 per person. In 2017, the country's median age was 39.3 years and it will reach 40.8 years by 2030 (Euromonitor International, 2018). According to Marine Harvest (2017a), there are over 21,000 fully employed people, either directly or indirectly, in the Norwegian aquaculture sector. The sector has seen a fourteen per cent increase in workforce from 2015 to 2016, and share of female workers makes up seventeen per cent in 2016 (Statistics Norway, 2017b).

According to International Salmon Farmers Association (2015) salmon farming is especially an important economic driver along the Norwegian coastline and in local municipalities such as Herøy, Skrova, Skjervøy, Austevoll, Frøya or Hitra. Especially, new technology that automates many roles in the processing part of the production can be a potential threat to jobs in these areas. Additionally, consolidations and the introduction of new innovative farming methods, like oceans farm, may lead to jobs being concentrated to a limited number of locations. The biggest threat to Norwegian jobs are nevertheless the development of land-based farming, which can take place in any part of the world regardless of eco-biological conditions. If jobs are moved abroad closer to the end market where labor costs are smaller, it can have a huge impact on Norwegian coastal municipalities. On the other hand, the lice problem can create new jobs and offer new business opportunities.

Technological Factor

According to Bloomberg, Norway is considered an innovative country, ranked as 15th in the world. Especially, the country scores high in researcher concentration and high-tech density. The Norwegian aquaculture industry is characterized by a high degree of technological innovations (Jamrisko & Lu, 2018). There is a good resource pool for research and development for innovative technology in salmon aquaculture industry. Norway is a pioneer of the salmon farming industry and attracts a variety of global talents to the country.

In terms of digitalization in the field, big data and artificial intelligence were introduced in the Norwegian aquaculture industry in April 2017. For example, big data shared by large players in the industry makes the Norwegian Centres of Expertise Seafood Innovation Cluster's AquaCloud able to predict the level of sea lice, two weeks in advance. Another example is a platform, powered by IBM's Watson, which also helps evaluate both financial and biological effects of proposed actions to successfully predict sea lice two weeks in advance (EY, 2018).

Norway is also active at fostering technological collaboration with other countries. For example, the country is experimenting offshore farming, which aims to avoid sea lice infestations typically spread in conventional small and overcrowded coastal farms. Furthermore, it tackles the water contamination from leftover feed (Jiji, 2017). In addition, China has delivered newly constructed offshore farming facilities, which are considered a major milestone (Xinhua, 2017).

Environmental Factor

As mentioned earlier, Norway possesses one of the most fitting ecological settings for salmon farming. Thanks to its long coastal lines and water temperature suitable for aquaculture, salmon farming has been flourishing in the country.

Farmed salmon produce less carbon and have higher food conversion efficiency compared to other land based protein sources. However, even though farmed salmon has lower environmental footprint compared to beef, pork or poultry, the salmon aquaculture industry still receives criticism for its environmental impact. The two biggest criticisms include its effects on the wild ecosystem, and water pollution. Escapes of the farmed species from pens and chemicals for lice treatment can interrupt the unique features of wild species. On top of harming the ecosystem, large amount of feces and waste from the farm will destroy and pollute the water (Knapton, 2017). More details are presented in the appendix IV.

When these facts are highlighted in the media and catch the public attention, they might play a crucial role in managing the global demand for salmon. Activists including Paul Nicklen and Kurt Oddekalv have aggressively pointed out the consequences of salmon farming on the environment. Paul Nicklen addressed the misconception of benefits of farmed salmon and Kurt Oddekalv argued that the scale of fish farming in Norway is unsustainable (Castle, 2017; Nicklen, 2003).

Legal Factor

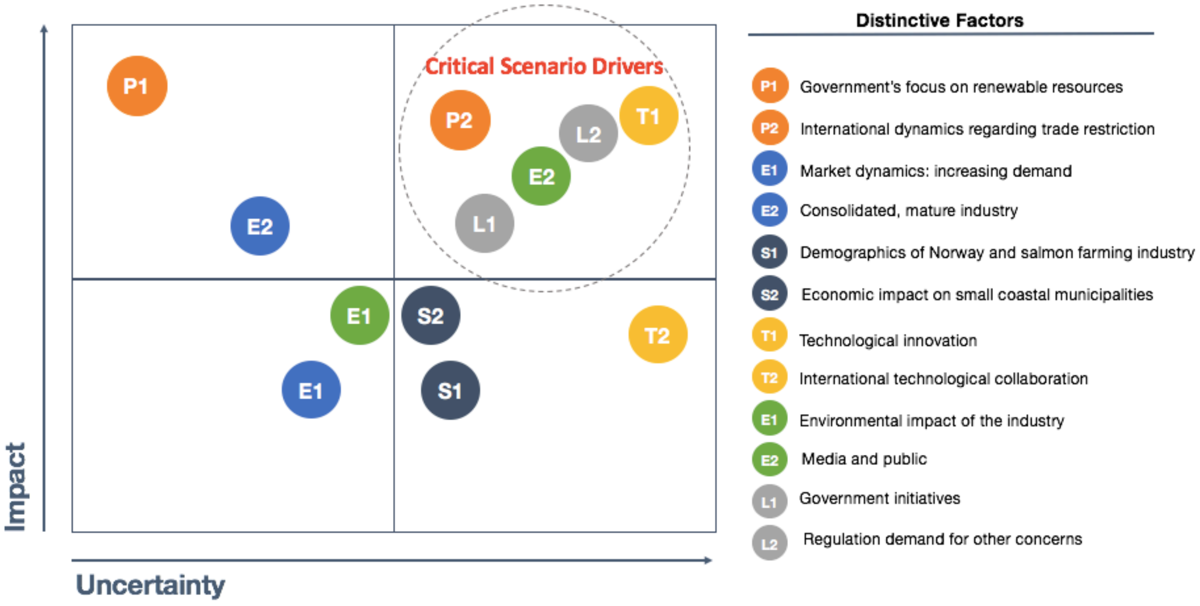
Norwegian government plays a big role in the country. Industries are characterized as heavily regulated, with a strong focus on sustainability in terms of environmental, social and economic aspects. The Ministry of Trade, Industry and Fisheries, through the Directorate of Fisheries, regulate the aquaculture industry. The main regulative document for the sector is the Aquaculture Act (2005), which contains relevant laws and regulations. The Norwegian Food Safety Authority receives the report of lice levels from the farmers. Moreover, the Norwegian Coastal Administration and the Norwegian Water Resources and Energy Directorate are involved with the regulation and control. Farmers need government-issued licenses to produce fish in the farms. More specifically, concerning sea lice, there are several policies including the traffic light system, development licenses and green licenses. These policies are explained more in details in section 3.1. The implemented policies are expected to improve the conditions and resolve the issues, but it is still uncertain what consequences they will bring out.

Other regulatory concerns related to the industry state health and safety issues. Today, the fish farming industry is ranked as second in Norway for working accidents. Therefore, the stakeholders argue that if the regulatory body fails to address this problem, it might hinder the further growth of the industry (Finne, 2017).

2.2.3. Drivers shaping the future: Impact-uncertainty matrix

Based on the PESTEL analysis, the trends are categorized into twelve distinctive factors, which are the most significant for shaping the future of the industry. Figure 4 presents an impact/uncertainty matrix, and the different factors are mapped out according to their impact and uncertainty. The factors placed in the top right corner are the critical drivers of the scenarios, which follow in the next section (2.2.4.).

Figure 4: Impact/uncertainty Matrix



The five critical scenario drivers are characterized by their high impact and high uncertainties of occurrence. These drivers are redefined as technology development and adoption, media and public, government initiatives and demand for regulations for other concerns, and international trade relations.

<u>Technology development and adoption</u>

Technological development can improve the efficiency and trust on the industry regarding sea lice problem through various tools. For example, through digital tools such as internet of things, more efficient data collection and effective decision making process can be feasible. Drones, robotics, artificial intelligence might be able to assist tackling the core and exterior of the problem (Dumiak, 2017). Moreover, block chain technology can facilitate the transparent value chain of the production, which is crucial for food trust. For example, by labelling each salmon product with the help of the technology, one can track individual level of lice. New technologies specialized for the efficient production include closed and semi closed farms, offshore aquaculture and recirculation aquaculture system, snorkel barrier, tarpaulin shielding skirt, laser, subsea pens, land based facilities, some of which are supposed to be able to shield salmon from lice (Mugaas Jensen et al., 2017; PwC, 2017; Sjøthun Røen, 2015). With the development license, innovative solutions are encouraged. As mentioned, a number of opportunities with high impacts lie ahead. However, a successful application and implementation of those are still uncertain.

Government initiatives & Demand for regulations for other concerns

The government and the regulatory institutions are on the horns of dilemma between boosting and limiting the production because of lice. This has an extensive impact, as this would directly shape the industry. How will the regulatory body be able to balance those two? And how will the policy makers include the concerns that have not been addressed thoroughly yet? For example, concerns including health and safety issues can be a crucial factor for the industry, if not resolved well (Finne, 2017). At the same time, these government initiatives are also very uncertain factor as quite many regulations for the industry are only at the beginning stage of the shift.

Media and public

How the media reflect and the public view the sea lice issue and farmed salmon will be another crucial driver for the future for the industry. Demand of farmed salmon can heavily depend on the publicity of the product such as how consumers perceive its environmental consequences. The popularity of salmon can vary, especially since the customers are becoming more and more aware of and interested in what they are consuming. To add, it is getting easier to access information, and once certain information is available, spread of the news is a matter of time and can bring out a huge impact. Nonetheless, the stance of the media is hard to define since one small instance can redirect the attention of the public and this contributes to the high uncertainty of the driver.

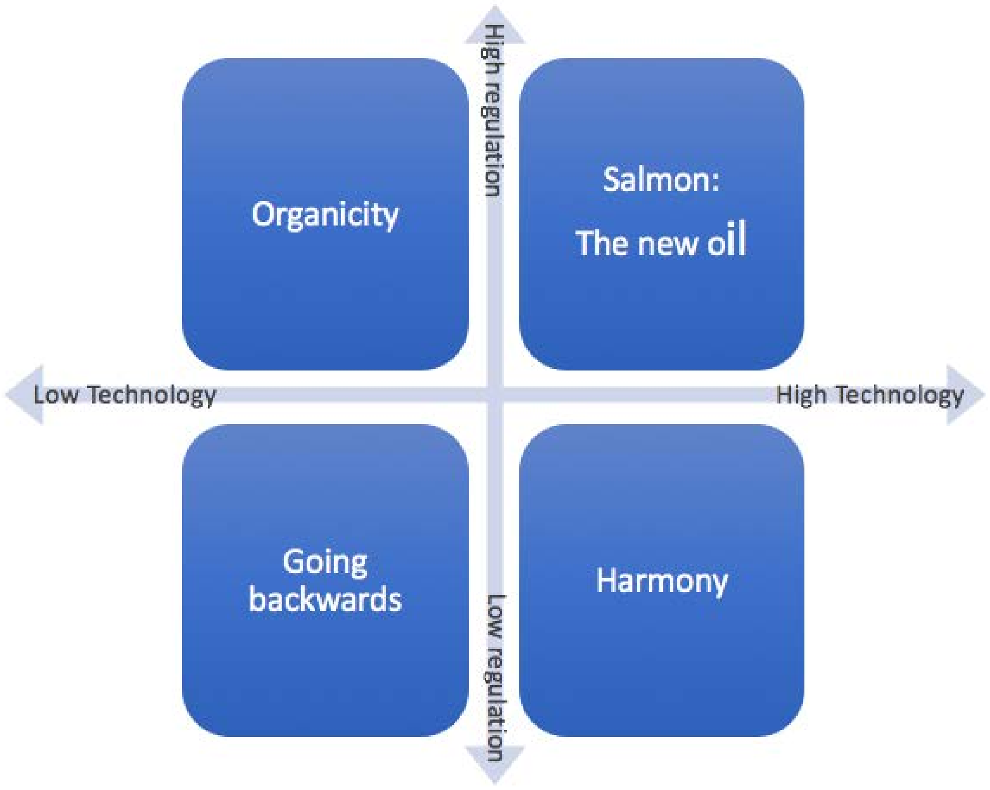
International trade relations

The major share of demand for Norwegian farmed salmon comes from outside of Norway. Therefore, international trade relationship is one of the most crucial driver shaping the future of the aquaculture industry. However, the dynamics of international relations is often very hard to predict, and crisis can occur at any time. Many complex factors can determine trade relations, such as protectionism and lobbying. For example, Vladimir Putin, the Russian president, signed a decree prohibiting the import from a number of countries including Norway in 2015. The effects from this were significant on export of salmon, since Russia is one of the five biggest importing countries (Norwegian Seafood Council, 2016). Therefore, international trade relations represent high impact and is of high uncertainty.

Each driver defined above is critical for shaping the future. However, to set up the two axes for plotting the future scenarios for salmon farming industry, we select the two least correlated drivers: technological development and innovation and government initiatives and demand for regulation for other concerns. Then, these are renamed as technology development and adoption (from incremental to disruptive) for the X-axis and government regulation regarding lice control (from low to high) for the Y-axis. We specify the definition of the two axes so that both factors refer to what impacts lice control. The level of technology development and adoption refers to those of the salmon farming companies. The government regulation implies the intensity of the authority’s control on the level of lice. That is, low level of regulation refers to a similar, or incremental changes from that of 2017 in terms of the level of lice restricted by the government. Each of the four scenarios are developed according to the X and the Y-axis. Figure 5 shows how the four scenarios are developed by the two axes.

2.2.4. A glimpse of the Norwegian aquaculture industry in 2050

Figure 5: Developing the Scenarios



<u>Organicity (incremental technology development and adoption, high level of regulation)</u>

Government has been a powerful player in the aquaculture industry. The Ministry of Trade, Industry and Fisheries has executed strict regulations within the aquaculture sector. For example, the restriction regarding the sea lice level has become even harsher; reporting is more demanding and precise, and level of lice allowed per fish is tightened. The traditional treatments have become less effective, which results in biological treatments mainly being applied. Norway keeps rather a traditional farming industry compared to other countries that have new technology. The industry is still fragmented, and small farms do not have the ability to catch up with other international players' technological adoption and application level. Some of the big international players slowly move their focus to other production facilities abroad where they are eligible for regulation that is more flexible and mass-production of the fish stock.

However, the strict regulations have been able to facilitate the maintenance of high reputation of Norwegian salmon. National and international media are in favor of the quality of Norwegian farmed salmon. Especially, the strict and clean production process and the industry's environmental impact on surrounding ecosystems are highlighted. The government also has managed to deal with the issues raised by salmon farmers concerning other aspects in the industry including the health and safety. The authorities are also looking into the possibility of expansion of the cleaner fish industry. To sum up, the productivity has shrunk, but the stable demand for Norwegian salmon eventually maintain the total production level.

Going backwards (incremental technology development and adoption, low level of regulation)

Thanks to the loose regulation regarding lice in salmon farms, production increased slightly in the beginning of 2020. However, towards 2050, because of the uncontrolled lice level, higher treatment costs and overall production costs lead to lower or even negative margins. The high lice level entails reduced global competitiveness due to lower brand perception of Norwegian salmon. Despite the availability of certain technological advancement, the Norwegian aquaculture industry has remained highly traditional and has implemented almost none of the new technologies available. Typical farmers have no clear direction or guidelines and need government or big players' support for implementing the new technology. However, the government is not too proactive in reducing the level of lice, and big-scaled farmers have no incentives to invest in implementing innovation. As a result, some of the most cutting-edge knowledge and expertise have fled to search for better opportunities, and Norway has experienced quite a loss of its talent pool.

Moreover, international media has spoken for the active environmentalists who are highly criticizing the country and the industry for prevail of the lice, not only in the farming sites but also in the surrounding ecosystem. These factors ultimately lead to lower brand value of Norwegian salmon. In addition, foreign players with higher competitiveness supported by high level of technology development and adoption level have become a hindering factor for the Norwegian salmon to generate the highest economic yields. The production level shows continuous stagnation. The industry is fragmented since a lot of the big international players slowly move their focus to other international production facilities where they can generate higher profit, so mostly small and medium sized farms remain in Norway.

Harmony (disruptive technology development and adoption, low regulation)

Since the number and capacity of traditional farming sites are limited, technological innovation is unavoidable to surge the production level. Not only the development of high-end technology for lice control and production efficiency is well settled, adoption of the developed technologies is smooth in the overall industry. New technologies enable the industry to expand the farming sites to alternative locations such as out in the ocean in addition to closed and semi-closed farms where the lice problem is eliminated. This has transformed the salmon aquaculture industry into a highly efficient business, where the use of digital tools including robots, internet of things, smart nets, and digital collaboration is widely spread for lice treatment and production. Technology increasingly replaces human workers and, the remaining human workers are in turn more specialized, and their main function is to program and maintain tools rather than mere manual work. Therefore, salmon aquaculture and lice control do not involve high level of physical activities anymore so that it is indifferent in regards of age level or gender. The aged population and female workers take bigger part in the salmon farming activities.

The level of lice is slightly lower than the current figures. The production quantity has increased with the help of new technology. The Norwegian aquaculture industry remains rather fragmented. Due to few changes in the 2017 level of regulation on lice, the government offers flexibility to farmers to decide on the level of investment on innovation. Especially farmers in areas with the most severe lice problem are investing in new technology, while farmers in less affected areas will choose not to invest. Due to the capital requirements of research and development, the biggest companies are the ones to lead the innovation. Therefore, there are free rider problems and externalities. The farmers with lower capability or willingness to invest in innovation can still benefit from the lower level of lice in neighboring farms. Thanks to the lower level of lice and the increased level of production, Norway can maintain its leading position in the global farmed salmon market.

Salmon: The new oil (disruptive technology development and adoption, high regulation)

Lowering the level of lice is one of the most important agendas of the Norwegian government. The policy makers have a strong focus on the sustainability issues including lice control but the policy implementation process takes long due to the Norwegian bureaucracy and conflicts between different interest groups. The need for rationalization to maintain low level of lice leads to innovation. This entails higher industry consolidation, where only a handful of enterprises compete to increase their efficiency and improve their competitive position. Since innovative lice control requires high capital expenditures and high research and development spending, there have been active mergers and acquisitions of small and medium sized farming companies.

Production and lice control have become comparatively more efficient, for example, the use of new technologies such as self-maintenance materials, and block chain technology have been able to control the lice in an effective way. The production level stagnates for a while due to the strong regulation and development of newly implemented technologies. As illustrated earlier, it takes time for new tools to be established stably due to the unique characteristics of long production cycle for farmed salmon. Thanks to the efficient control of lice, Norwegian salmon continues to sustain its image of strictly regulated high quality products. However, certain customer segments avoid Norwegian salmon, as they perceive the products to be less organic or natural due to the new way of farming. Still, the industry generates less negative environmental impact due to decreased level of lice. Additionally, since the regulation enforces most of the players in the industry to search for new solutions, there will be less free riding problem compared to the scenario with lower regulations.

These four different scenarios suggest different landscapes of the aquaculture industry in 2050, and imply the need of appropriate level of governmental intervention with regulations and support for technological innovation and following adoption for optimization of the problem. In the following section, we will measure the current policy schemes of the Norwegian government, and come up with the recommendations how the government can improve the effectiveness of the policies to reach its 2050 goal.

3. Discussion

In this chapter, we introduce the current Norwegian policy schemes for combatting sea lice challenges, as well as their merits and demerits. Then, based on our findings from the analyses combined with the evaluation of current policies, we present the implications and recommendations for the robust future of salmon farms.

3.1.Measuring the current policy schemes

An efficient and impactful policy instrument should be able to promote the economic, environmental and social benefits to boost the competence of the industry. At the same time, the regulations are to mitigate the risks of negative consequences that can bring out further damaging impacts in the industry as well as others.

The main regulatory tools of the Norwegian government are explained in the following. The legal limits on sea louse abundance on farmed fish include mandatory reporting of lice data to regulators for protection of coastal waters that can support some of the remaining wild Atlantic salmon stocks. Based on these, the regulatory body has implemented the traffic light system, along with development licenses, and green licenses.

Traffic light system: Implemented by the Ministry of Trade, Industry and Fisheries from October 2017, the traffic light system was developed to regulate the sea lice level by offering incentives of growth capacity in salmon farms. The coast is divided into thirteen different areas whose corresponding color of green, yellow and red define the current level of lice in each area. Areas with green light will be offered annual growth capacity of two per cent while ones with red will obtain a penalty of reduced MAB. In yellow areas, the allowances will remain the same for now. The production capacity of those with red and yellow lights will remain unchanged until the next evaluation round in 2019 and this term is expected to give the industry proper time to adjust to the new system. In addition, farms that are able to keep a low level of lice (less than 0.1 lice per fish), are eligible for a six per cent increase in biomass regardless of which area they belong. In total, the overall long-term MAB growth is expected to be around 24,000 metric tons per year. This implies an annual growth of two per cent. An entity with licenses in one area can apply to move a share of its capacity to an adjacent area. Thus, all entities could produce in two areas with a joint MAB allowance (EY, 2018; PwC, 2017).

Through the traffic light system, the regulatory bodies encounter an easier and more efficient control for numerous farms in Norway. By grouping the salmon farms along the entire coast from Agder in the south to Finnmark in the north into thirteen zones, effective use of resource is viable rather than monitoring approximately 1,000 farms. Moreover, a six percent increase in biomass can work as a powerful incentive tool to encourage the farmers to resolve the lice issue in their own optimal way.

Nonetheless, some of the salmon farmers have expressed negative points of view. Firstly, since different farm sites are bounded in the same zone, negative externalities can take place. It is unfair for the farmers that one has to take the risks of neighboring farms according to the regulation. There might be free riders who take advantage of the blind spot. Ola Braanaas even stated that "a Norwegian salmon farmer would go to court if she or he has to reduce biomass because of other farmers' problems" (Castle, 2017). The externality problem will result in conflicts within the region and reduced efficiency, which are the opposite of intended outcome of the policy. On the other hand, Marine Harvest, the world's biggest salmon producer, expressed that the methodology is questionable and the protocol is premature. Some environmentalists and activists think that the system is not strict enough (Castle, 2017). Therefore, despite its efficiency, if the Ministry cannot adjust the drawbacks, the traffic light system might bring about severe unintended negative consequences.

Development Licenses: The development license system facilitates the development of technology that can tackle the important environmental or territorial challenges the industry faces. The system is considered a temporary arrangement that proposes licenses to certain projects based on innovation and resource requirements. The development license system also requires the farmers to share the developed technology to show industry-wide enhancements.

In 2017, an ocean-based farm by Nordlaks Oppdrett AS, semi-closed farm technology by MNH Produksjon AS, closed farm technology by AkwaDesign AS, and closed farm technology by Marine Harvest Norway AS received the license. This recent program's deadline was 17 November 2017, and there are still number of applications, which are not processed yet. This implies that there will be more innovative technologies available in 2018 (EY, 2018).

The development license is a good initiative of the government to encourage the innovative solutions to resolve the sea lice problem in the salmon farms in Norway. However, the system is such an exclusive scheme for certain targets, which are able to conduct research and development that is costly. Therefore, in reality, small-scaled salmon farmers have low chances to apply for the license system. Moreover, the current evaluation method puts weight on the projects with the highest investment costs and the most innovative solution. This might keep the institution from rewarding the solutions that may help solve the challenges in a more cost-effective way.

Green Licenses: Green licenses were initially issued in 2014 to tackle environmental and territorial challenges. In 2011-2012, the authority designed this policy tool to encourage the farmers to adopt new solutions for lice, by issuing higher level of MAB. The licenses were sold to salmon farmers under the condition that they will practice new technologies to effectively prevent the sea lice and escapes (Hersoug, 2011). For example, SalMar ASA earned sixteen of the licenses for its Midgard pen construction, surveillance of rivers to control the fish escapes, and the use of lumpfish as clear fish (SalMar, 2018). There were 225 applicants for the licenses, while only 45 spots were available. Many applications were rejected because of the formalities. There have been no changes in green licenses in 2017 (EY, 2018; Nikitina, 2015).

Green licenses could be, and still can be an incentive for certain group of farmers to actively engage in innovation. Yet, the license program has its own limitations. To begin with, the scheme is considered complicated. The two goals of the Ministry include both regional priorities and diverse farming structure. Moreover, the environmental criteria differed among the licenses since there is a limited number of licenses available, they can cover and offer opportunities only for a small part of the whole production sites (Hersoug, 2011). Big part of the criticism against the license is that its administration process is not reliable and efficient. Furthermore, since the program is still in its experimental stage and to be evaluated, the results are not certain (Nikitina, 2015).

3.2.Implications and recommendations

The quantitative and qualitative analyses provide us with information, which shows that the industry continues to face challenges, in both the short and the long-term. Even though the farming companies are investing more in lice treatments, the biomass loss from the reduced growth is still increasing. In the short-term, the surge in salmon prices has increased the margins and profitability of the farmers, which might seem to compensate the problem. The reduction of supply due to stagnation in biomass growth is one of the factors regarding the rise in salmon prices. PwC (2017) and Nofima (2017) estimate the total cost per kilo sold salmon to be around NOK 36 in 2016. In the beginning of June 2018, when this thesis is written, the salmon price is NOK 65/kg. The price has peaked earlier in the year at around NOK 80/kg. It is clear that farmers gain higher profits from higher price level, and this might blind them in their decision-making process for the long-term planning of lice control. One does not need to look far back to see that this short-term profit can be expensive in the long run. For example, in May 2015, the average price was NOK 37/kg; 2014 had four months when the price was lower than NOK 36/kg and; in 2012, the average weekly price over the whole year was NOK 26.58/kg (Fish Pool, n.d.). If prices are to drop to these levels, farmers will lose money and the industry may experience the same result as in the oil price drop in 2014 when thousands of people lost their jobs and a number of oil related companies went bankrupt. Additionally, salmon farmers do not have much flexibility if the prices were to drop because the duration of the production process from hatching of eggs to harvesting of adult salmon is normally between two to three years.

That is, salmon farmers may fail to manage their strategies adequately and when they mismanage the lice problems underestimating the market dynamics, it is likely that total operational costs are above the market price for a certain duration of time. To achieve the goal of 2050, the government should be able to prevent the industry's profitability from being dependent on the market price level and encourage the farmers to proactively deal with the lice issues.

In order to avoid a scenario where operational costs are higher than the salmon price, it is necessary that the government provide the right guidelines. Then, the farmers and the government can cooperate to find a solution to the lice problem. It is in both parties' interests to tackle the issue so that Norway does not lag behind other countries that are putting a lot of effort to outcompete the reputation of Norwegian aquaculture. Especially if land-based farming becomes a common method of production, Norway's main advantages related to its geological characteristics will be disregarded.

According to our qualitative analysis, two cases suggest that the government might be able to meet its established target; scenario 3 (Harmony) and scenario 4 (Salmon: The new oil) are the most desirable cases where the industry is able to boost the production level. Scenario 3 and scenario 4 assume a high technological development and adoption level, however, these two have contradicting size of the government in terms of lice regulation. Therefore, we present two different recommendations for these two scenarios.

In scenario 3, the government decides to maintain the current degree of the regulation in terms of lice level while the technological development and adoption level is high. The low level of government enforcement for lice develops externality issues among the farmers. The "emission" of salmon lice by farms and the potential production output limits suggest that the lice can be considered an externality, produced by the salmon aquaculture industry. Stakeholders have tendencies to blame each other especially when facing problems and challenges, which often leads to conflicts. Salmon farmers and the aquaculture industry is not an exception, as stated earlier in the previous section. However, the negative costs related to lice can be internalized by the incentives and regulations. We recommend the future policy makers to put emphasis on internalizing the externalities of lice by incentives in scenario 3. Appropriate regulatory design and the compatibility of regulatory measures of fish farmers' incentives will significantly influence costs incurred by the regulations as well as the effectiveness of the regulations.

To begin with, the Norwegian government can offer reward schemes to farmers with good lice treatment practices, as incentives. The government is already implementing a reward scheme through the traffic light system. For example, the authority allows six per cent of growth for certain farms with low level of lice (below 0.1 adult female lice per salmon), regardless of the condition in the respective production zone (PwC 2017). We suggest expanding the incentive schemes. The regulatory body can offer different incentive regimes to different size of farming companies, since a unified incentive system for farms with different properties will not entail the most efficient outcome. For example, on one hand, the authority can propose tax incentives for small and medium sized companies, who lack the resources to devote themselves to research and development. In fact, high tax rate and regulations are considered one of the highest obstacle for running business in Norway (World Economic Forum, 2017). On the other hand, improvement of the development licenses, and research grants can be good incentive tools for big sized salmon companies, which actually possess capacity to recruit talents for research and development. This can create more jobs such as treatment developer and sales personnel of the products and become a good practice for other salmon farming countries struggling with lice. The projects in the research and development process might fail sometimes from lack of experience and budget, but numerous trial and errors are valuable for potential improvement in good practices. As mentioned earlier, the Global Competitive Index states that insufficient capacity to innovate and access to financing are hindering the business development in Norway (2018).

In scenario 4, the government imposes strict regulation for lice and the Norwegian salmon farmers are exposed to wide variety of innovative technology available. It is important that the restrictions should be designed not to hinder but strengthen the competitiveness of the industry while achieving the goals of reaching economic, biological and social sustainability. For example, the restrictions and regulations for salmon production in Canada have eroded the strength of the industry (Krkosek, 2010).

From the benevolent social planner’s point of view, the government should aim to maximize the total welfare of the society. To minimize the duration of the stagnation of production level as well as to compensate the loss from mergers and acquisitions, the government can apply temporary flexible lice-level restrictions for a certain period. When the government first introduces the new lice regulations, it should allow farmers to be able to prepare through research and development for a few production cycles before the regulations are actually enforced. This way, the farmers will be able to continue production at a 2017 lice level, while enabling them to develop new technology that will prepare them for the new regulations. With the majority of the big companies adopting closed and semi-closed farm technology, the overall level of lice in the area will decrease. This allows a group of smaller farms to keep producing in a traditional way as long as they do not exceed the regulation thresholds. That is, the government avoids the outcome of heavy consolidation that would naturally occur due to high research and development costs, if all farms were to engage in closed production.

Furthermore, to attract a wider range of consumers including the ones who are skeptical about the new production methods, a collaboration between public and private sectors is encouraged to market and position the new salmon. The marketing campaign should highlight the reduced negative impact on the environment and that the quality is as good as traditionally produced salmon.

Lastly, the actual production level of the farms has historically been lower than what is regulated by MAB and the main reasons for this trend is from the sea lice. However, once the damages from lice problem slow down, the government should measure the possibility of adjusted MAB that the farmers do not hesitate to fully utilize the given MAB level. This can be either with extra buffer stock or with calculated average MAB for certain period. If farmers are too afraid to reach the limited biomass level, some of the farm facilities will be left obsolete.

4. Concluding remarks

4.1. Summary

The aim of the thesis was to quantify the indirect costs related to lice and examine the implications of the indirect costs for the government to reach its production goal for 2050. For the Norwegian government to achieve the target and to keep the industry sustainable, solving the lice challenge is inevitable.

The results from the quantitative analysis show that not only the direct costs from delousing treatments but also the indirect costs from biological factors are higher today compared to earlier studies. Additionally, heterogeneity exists between the regions as sea lice have a bigger impact in the south than in the north. This implies that different regulations and incentive schemes should be applied in different regions.

Technological development and adoption as well as government initiatives are the most critical drivers that shape the future landscape of the industry. Assuming the high level of technology, the government should either offer different incentives or support a preparation period for farmers to internalize the lice and treatment costs. These actions depend on the intensity of lice regulation. If the authority fails to address the challenges properly, the industry might end up falling behind the international competitors. No single regulatory tool is without flaws, but a coordinated application of several tools may prove fruitful.

To conclude, our recommendations foster a win-win scenario for both the government and the aquaculture industry by ensuring a good guideline for the 2050 goal as well as a healthy development of the industry.

4.2.Limitations and future research possibilities

There are different limitations of the two analyses conducted in this thesis. The quantitative analysis is based on several assumptions and estimations rather than actual numbers. This is due to the lack of raw data available, but the assumptions and estimations are reasonable as they are based on information from reliable sources. Thus, we expect the bias created by the lack of real data to be insignificant and will not affect the main results of the study. In addition, the analysis uses historical data, which may not accurately depict the current and future situation of sea lice. For the qualitative analysis, the four scenarios illustrate the holistic landscape of the industry, and the recommendations are based on this. Thus, our analysis might lack or underestimate the significance of the individual farm specific factors. Furthermore, our thesis does not fully reflect the insights and opinions of various stakeholders and experts or suggest specific figures.

However, this thesis provides a good foothold for further research within the area of sea lice. It would especially be interesting to conduct an analysis and see if it is possible to figure out which delousing treatment is the most effective to use at different stages of the production cycle, both in terms of removing the lice and the cost of each lice removed. Additionally, a biological study on the different region-specific geological factors can help us understand the heterogeneity of the different regions of Norway. Such a study will make it easier for farmers and regulators to predict the future and plan for it accordingly. Another study could try to quantify the effect the reduction of biomass supplied due to sea lice has on the market price for salmon. This could validate whether the indirect cost of salmon lice have any effect on the gross profits of salmon farmers. Furthermore, this paper presents an analytical tool, which is capable of creating projections on the implications of the ongoing trends of Norwegian salmon aquaculture focusing on the lice problem. However, for a more in-depth analysis, we recommend a collaborative research with relevant stakeholders from both private and public sectors. This can help highlight the specific farm level factors in different regions such as geographic characteristics for the research.

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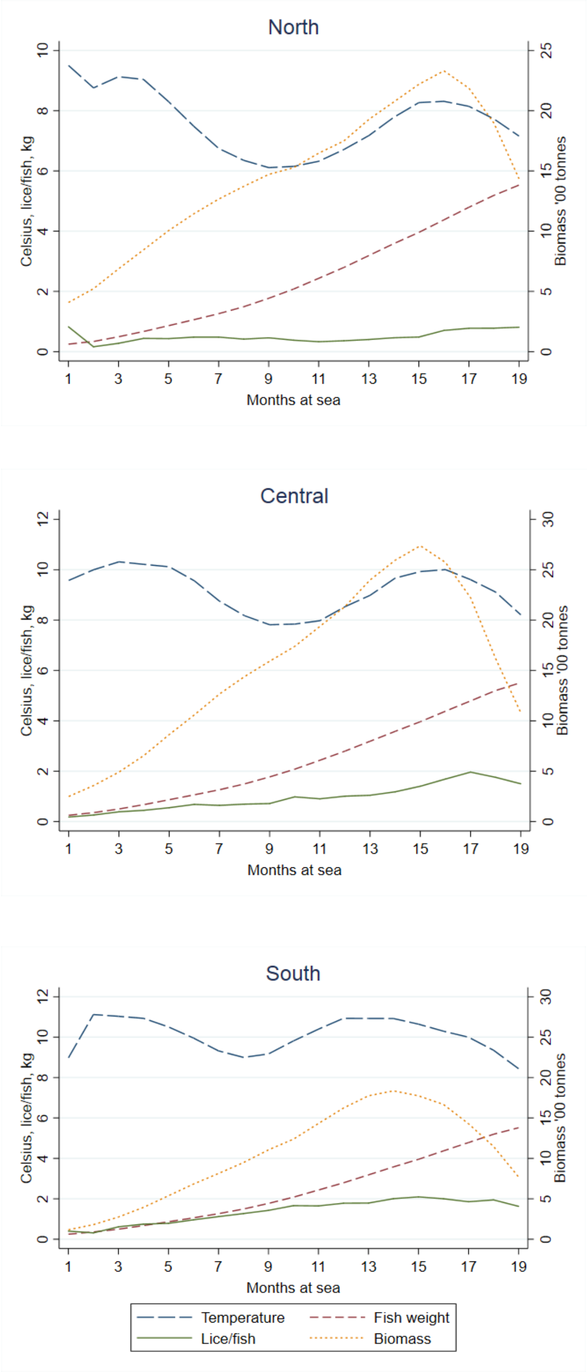
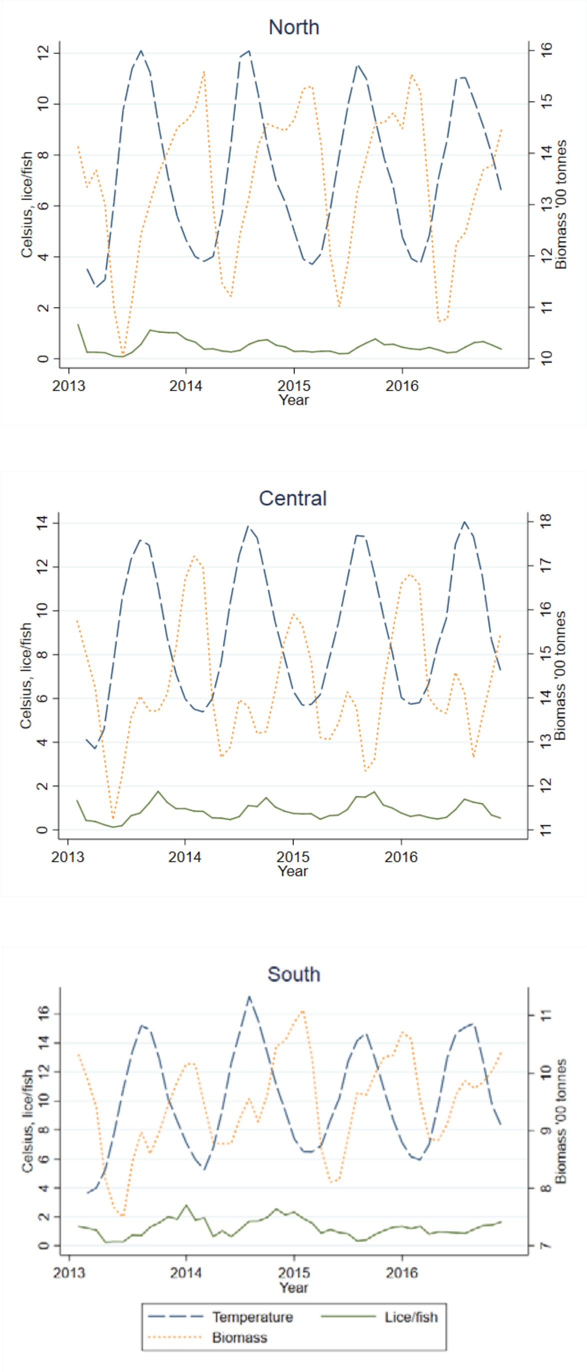
6. Appendix

6.1. Appendix I: Development of biomass and lice data





6.2.Appendix II: STATA Code

```
** Fixed effects regression and prediction in no-lice dataset**
use mergeddatasets.dta, clear
xtset locnr mas
xtreg lngrowth mas l.biomass l.weight l.totlice
c.l.totlice#c.l.totlice
c.l.totlice#c.l.weight c.l.totlice#c.l.biomass
c.l.totlice#c.l.meantemp
c.l.totlice#c.l.treatment l.meantemp
c.l.meantemp#c.l.meantemp Y2013-Y2016, fe
use nolice.dta, clear
xtset locnr mas
* Codes for Duan's estimator*
predict growthnolice
predict unolice, residual
gen unoliceexp = exp(unolice)
summarize utnoliceexp
gen duan = r(mean)*exp(growthnolice)-1
* Calculations of monthly biomass lost due to sea lice*
bysort locnr: gen git = (lngrowth)*biomass[_n-1]
bysort locnr: gen git2 = (duan)*biomass[_n-1]
gen deltagit = git2-git
**
** Codes for calculating the marginal effects of lice at the
different regions**
margins if north, dydx(c.l.totlice) atmeans
margins if central, dydx(c.l.totlice) atmeans
margins if south, dydx(c.l.totlice) atmeans
**
```

6.3.Appendix III: Treatment costs

Treatment Method	Price
Cleaner fish	
• Gold sinny wrasse	kr 11.61/fish
• Corkwing wrasse	kr 13.16/fish
• Ballan wrasse	kr 24.40/fish
• Other wrasse	kr 17.75/fish
• Lumpfish	kr 20.03/fish
Mechanical	
• Thermal	kr 0.45/fish treated
• Flushing	kr 0.38/fish treated
• Freshwater	kr 1.26/fish treated
Chemical	
• Traditional chemical baths	kr 0.46/fish treated
• Hydrogenperoxid baths	kr 0.72/fish treated

Source: Nofima 2017

6.4.Appendix IV: Environmental impacts of salmon

Both farmed and wild salmon have their own merits and demerits when it comes to the environmental impact. Wild salmon industry alone can be blamed for overfishing, which could lead to decreased stock and destroyed underwater ecosystem. Carbon footprint of far distance transportation is also considered as a serious issue.

On the other hand, most farm raised salmon are faced with different environmental concerns. Internal environmental concerns include fish health and welfare in the farm. The Norwegian Animal Welfare Act of 2010 states that animals have an intrinsic value. Particularly, fish are sensitive to its environmental surroundings, such as temperature variations, currents, and algal blooms. On one hand, farmed fish are provided with a protected environment with few natural enemies, regular feed with sufficient nutritional ingredients and vaccination. On the other hand, in fish farms, they are also subject to human control including transport and chemical treatments. Moreover, fish populations in the net pens are very dense, resulting in a relatively high risk of disease and limited access to exercise and positive stimuli. Furthermore, the fish are extensively handled in connection with transport, vaccination, stripping (brood stock), and slaughter. Breeding and genetic engineering strategies can lead to permanent changes of the fish populations that may be of relevance for animal welfare.

One of the biggest external concerns is the threat to the wild salmon population and the ecosystem. The likelihood of local nutrient pollution from waste feed and fish feces and chemical pollution from the use of treatments is widely criticized by the media. Moreover, according to WWF, accidental release of fish can transmit the parasites or diseases to the surroundings (WWF, n.d.). Moreover, the feed production generates a lot of wasted resource. Traditionally, most farm raised salmon live on the feed that consist of smaller fish caught in the sea, or processed through several procedures, which is not considered sustainable.

However, salmon aquaculture does not only have the negative environmental aspects but also benefits to the environment. First, it produces less greenhouse gas emissions compared to other protein sources. According to SINTEF Fisheries and Aquaculture, NTNU and SIK(Institute for Food and Biotechnology in Sweden), 1 kilogram of farmed salmon fillet which is eaten in Paris results in approximately 2.5 kilos of CO2 equivalents. In comparison, the carbon footprints for other food products are far higher: 30 CO2 equivalents per kilogram of cattle, 5.9 CO2 equivalents per kilogram of pork. In addition, most of the CO2 emissions associated to salmon farming is related to the production of fish feed. Thus, the biggest improvement can be executed in feed utilization, ingredients and other measures aimed at the feed (FHF, 2009).

Moreover, feed conversion ratio of salmon is much lower compared to other protein sources such as poultry, pork and beef. It is an important factor when it comes to the sustainable environment concerning the resource scarcity of the planet. Feed conversion ratio is a measurement of the efficiency of how much feed can be actually converted to meat produced. To produce 1kg of meet, approximately 2kg of feed is required for chickens, 3.5 for pork, 8 for lamb and beef while 1.18kg is needed for salmons (Leroy, 2015).