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Fish health implications for Norwegian aquaculture

An industry analysis uncovering the economic impact of fish health-related issues in aquaculture

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Acknowledgments

With this thesis, I conclude my master's degree at the Norwegian School of Economics. It is a Master of Science in Economics and Business Administration with a major in Business Analysis and Performance Management and a minor in Financial Economics. Investigating one of Norway's most important industries has been interesting and serendipitous. Fish health is an important topic now and increasingly so in the future.

Having Linda Nøstbakken as my supervisor has been a huge privilege, I could not have done this without her. She is patient, assiduous, discerning, and the main reason I can turn in the thesis this semester. Thank you for supporting me through good and bad times.

My nearest and dearest support me through thick and thin and facilitate everyday life so I can perform at the university, during my workouts, and at my job. Thank you!

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1. Introduction

A growing concern for the aquaculture industry is bio-risk development. Atlantic salmon do not have their natural habitat in the growing pens, and it is causing the industry to lose batches because of exposure to parasites, viruses, and bacteria. It is facing obligations of reduced biomass and negative publicity caused by a growing concern for fish welfare. This is a composition of problems that have led to the rise of particularly to segments within the supply chain in aquaculture, fish health and cleaner fish. The fish health segment has grown a lot since 2010 and its profitability correlates with remedy usage. The cleaner fish segment has gone from having a revenue well under NOK 30 million in 2010 to about NOK 650 million in 2017.

Throughout this thesis, the goal is therefore to answer the following question: *Will fish health-related issues have an economic impact on the aquaculture industry now and going forward?*

To answer the question, I have structured the thesis into three main parts. The first part gives an account of the regulatory development of aquaculture, the cost structure, and the product. The second part is an explanation of the methods used in the analysis. The last part consists of qualitative and quantitative analyses of fish health-related businesses in the supply chain of aquaculture.

The main results in this thesis, are that the biological threat is indeed on the rise, and the profit generated from fish health and cleaner fish is high. There is a high demand for services tackling these problems, and cleaner fish is a very good example of how considerable this development has been. However, the emerging segments are not alone in offering services to mitigate the bio-risk. Well established segments as feed, eggs, and smolt are increasingly trying to develop methods to alleviate the fish health-related problems.

Other theses have investigated related issues. Tvete looked at challenges with land-based farming and presented a cost comparison between the two solutions (Tvete, 2016). Bundli and Liltvedt gave business participants, regulatory authorities, researchers, and the broader community awareness of priority areas within the fish farming industry through their conceptual framework (Bundli & Liltvedt, 2012). Aubell and Hamarsland looked at the effects of Production Area Regulation and among their main findings were that profits per production license increased by NOK 410,485 (Aubell & Hamarsland, 2018). I believe the thesis most closely related to this, is by Berle and Rim investigating indirect cost related to lice and its implications for the governments’ 2050 goal (Berle & Rim, 2018). The results showed that indirect costs have increased compared to earlier studies.

The financial data reported in this thesis show that producers are experiencing good returns with margins well above the best yielding industries. One should subsequently believe that it is in their own best interest to invest heavily to overcome the challenges explicated in this thesis.

2. Regulatory development of aquaculture

This chapter is meant to give an overview of when regulations have been introduced, and a short explanation of its content and intent. The focus areas of each regulation mentioned in the following review are geographical distribution, district consideration, ownership and agent size, environment, fish health, remuneration and bidding round, and development of aquaculture. They specify criteria on who is eligible for permits, the maximum allowed biomass (MAB), or what should be emphasized when prioritizing between two applicants.

Considerations of localities and operators have changed over time, where district politics was the focal point of decision making early on. At the onset of the aquaculture industry, increased economic activity along the coastal line was prioritized. The present-day discourse has shifted the attention to environmental matters and to the question of operators' capability to pay remuneration for permits.

The first aquaculture act was temporary and carried the title *"Temporary law from June 8th, 1973 about construction, establishing and expansion of facilities for roe hatching and fish farming".* At that time there were 287 facilities for salmon and trout. The fisheries act's first regulation was decided on November 16th, 1973. Applications for permits should contain information about *"the operational leader's experience with aquaculture, qualifications"*, *"the facilities size and capacity, technical and financial"*, *"quantity, quality and environment I saltwater and/or freshwater"*, and *"Access to power, cooling and production capacity"*. It limited all facilities to a maximum capacity of 8000m^3 (The Directorate of Fisheries Institute of Marine Research, 1974). In this period a total of 91 permits were allocated, and in 1977 the government halted the distribution of permits (Mikkelsen, 2018). In May 1981, the first permanent aquaculture act was constituted. Contrary to the temporary act, the new law had a purpose paragraph containing generalized statements regarding how the industry should operate. This year, 50 permits of 3000m^3 were allocated. Only a couple of years later, in 1983, a temporary regulation changed the size limitation. New facilities could be 5000m^3 and facilities smaller than 3000m^3 could expand. In 1984, 100 permits of 5000m^3 were allocated (Mikkelsen, 2018).

In June 1985, only four years after the first permanent aquaculture act, the government changed the law. The new act had a shorter purpose paragraph stating clearly its ambition to become profitable and sustainable for the district regions. Regulations regarding scientific purposes, broodstock facilities, and coercive measures were established in this period. 150 permits of 8000m^3 were allocated across the country and 30 permits of 12000m^3 were allocated in Troms and Finnmark (Mikkelsen, 2018). In the regulations for allocating permits in Troms and Finnmark, there were several points stating prioritization between applicants with female owners or employees. When two applicants were deemed equal, one should prioritize the company with a higher share of women (Mikkelsen, 2018).

The first regulation on restricting production beyond licenses was decided in February 1996. It implied feed quotas of 1000m^3 with an upper limit to the fish concentration of 25kg per cubic meter and contributed to increasing the focus on a sustainable district industry. Between September 1998 and December 2000 five regulations regarding production restrictions were implemented. The regimen with feed quotas and concentration control demanded frequent adjustments to avoid reprimands from the EU (Mikkelsen, 2018). Salmon lice had become a problem for the industry, and the government implemented lice counting from March to December, at least monthly and every other week when water temperatures rose above 9 degrees Celsius.

Reporting changes in ownership structure became compulsory, and one relied on obtaining a new license to operate. To limit market power, one had to get approval when collective MAB volume went above 10% and 15%. No one could go above 20%. Recompense and fees for new permits were established and varied from case to case. An electronic system for reporting feed quotas and production-regulating measures was implemented. Those who did not report electronically had to pay a monthly fee.

The first regulation regarding technical standards was set to limit the number of escaped fishes. Sea-based facilities had certain demands regarding shape, dimension, execution, installation, and operation. This was the Norwegian Standard and the different localities should be classified in line with these specifications (FOR-2003-08-12-1052, 2003).

Changes in The Food Act had consequences for several regulations within aquaculture and were implemented for the sake of public health. Following the changes in the Food Act, a regulation involving the food safety authority was implemented to promote animal health and secure safe industry funds. From now on, the food safety authority should play an active role when evaluating applications for establishing or increasing aquaculture production. Regulations for internal control took a systematic approach to execute the measures given by the aquaculture legislation. The internal control should be adjusted to different characteristics within each respective facility. In December 2004, the predecessor of The Aquaculture Act intended to advance profitability, competitiveness, sustainability, and fish welfare through a comprehensive regulation with seven chapters and 62 paragraphs.

New rules on ownership limitations. To acquire more than 20% of national permitted MAB, one had to get a permit from the department of fisheries. No one could obtain more than 35% of national permitted MAB and the regional limit of 50% was unchanged. The Salmon Allocation Regulation changed MAB from 25 kg per m^3 to 65 kg per m^3, except Troms and Finnmark where the MAB was 75 kg per m^3. This meant that the producers could increase their revenue and profit.

The Aquaculture Act was implemented to prepare the aquaculture for future endeavors to create a profitable, sustainable, and competitive industry, shifting the focus from who owns the business to how it is operated. The government aimed to reach these goals through increased adaptability, better capital access, and a more liberal market in general. The act maintained the environmental and health focus from earlier legislations and contained chapters that parsed out the details. Ownership limitations became stricter one year after the liberalization. To acquire more than 15% MAB, you had to get a permit from the ministry and the upper limit was set to 25% (The Aquaculture Act, 2005).

In October 2006 a regulation on slaughter and production facilities for aquaculture. The Food Safety Authority had to approve the facility, equipment, operations, etc. to ensure the safety of livestock and wild animals in the area. In 2007, coerciveness was increased. In cases with the danger of material adverse effects on the environment, this new regulation should be enforced to give a strong incentive to comply with legislation.

From 2007 to 2008 several regulations regarding virus, contagious disease, treatment methods, and transport were created to protect the fish from unacceptable conditions. In June 2008, the operational regulation was updated to promote good fish health and welfare. It contained general statements on how to deal with these implications. In June 2009, special demands for aquaculture in and by salmon-watercourses and salmon-fjords was stated. The regulation should deal with operators of aquaculture facilities, slaughterhouses, operational facilities, and net-cleaning facilities. If operations were conducted in a national salmon fjord, one had a two year period to relocate.

The title of the NYTEK-regulation introduced in 2011 stated; *"Regulation on demands regarding the technical standard for sea-based aquaculture plants".* The intent is to prevent fish from escaping plants through securing a proper technical standard. This entangles everyone in the business of sea-based aquaculture including goods- and service suppliers and accredited authorities for certification and inspection. There are also several essential components of the operation that must meet requirements set by Norsk Standard. The same year, a regulation made it possible to increase MAB for regular aquaculture concessions by 5% in Troms and Finnmark. Recompense was set to NOK 150,000 for Finnmark and NOK 500,000 for Troms (NYTEK-regulation, 2011). In 2011, the ban to transport or trade roe from broodstock which has tested positive on PDV to aquaculture facilities outside the zone was lifted (Mikkelsen, 2018).

In December 2012, a regulation was introduced to combat the development of lice in aquaculture facilities. It aimed to reduce the frequent appearance of lice and mitigate its damaging effects. The report specified plans, measures, and lice counting schemes to deal with salmon lice.

Green permits were advertised, 45 in total. These permits made the farmers commit to solutions that dealt with some of the environmental challenges to a higher degree compared to traditional aquaculture. The purpose of the green permits was: *"contributing to facilitate sustainable and competitive aquaculture that will create activity and value creation along the coast and stimulate the realization of new technological solutions or operations that initiate a reduction of environmental challenges regarding farmed fish and contamination of salmon-lice"* (Regulation on granting permits, 2013). Later that year, the sanctions if The Aquaculture Act was infringed upon, became stricter if there was danger of causing severe damage to the environment.

The regulation of February 2015 aimed to reduce the risk of genetic influence from aquaculture on wild salmon populations. It stipulated an amalgamation of aquaculture permit holders for planning and covering of expenses to reduce the amount of escaped fish. In June 2015, a regulation with a time-limited offer to increase MAB with 5% if one paid a recompense of NOK 1,000,000 and accepting a stricter regulation of the number of lice and lice treatments. Development permits were made available through the regulation from November 2015 and are an attempt to increase investment in technology and innovation projects.

The salmon lice regulation was changed in March 2016, so that the period for coordinated treatment was extended across the country. It became the same for every county and it lasted from March 5^{th} to June 25^{th}. The regulation of production divided the Norwegian coast into 13 different zones, where the production capacity of commercial fish production is managed according to the rules set in the regulation. The division and rules followed by the regulation try to mitigate the effect of environmental impact in the production area. Depending on the prevailing situation in the production area, operators can increase or decrease their capacity. In March 2017, the coordinated treatment against salmon lice was repealed. The maximum quantity of lice remained unchanged except for the period when smolt leaves the river. Since the exodus occurs at different times in the country, Norway was split into two separate regions, south and north of Nord-Trøndelag. Measures to mitigate, limit, and fight pancreas disease (PD) were implemented through regulation from August 2017. Accredited laboratories, service vessels, service personnel, and net cleaning facilities operating in a PD zone were affected by this regulation. The operators would regularly test for salmonid alphavirus (SAV), PD, and vaccinate the fish. In December 2017, the capacity increase was granted through a regulation affecting green production areas and exemption localities. The Food Safety Authority should evaluate if facilities fulfilled the demands for lice quantity and medical treatment. The collected capacity increase could not exceed 6%, including the acquisition of a 2% capacity increase in green production areas.

A regulation on dealing with cleaner fish was introduced in April 2018. It contained decisions on how cleaner fish is handled concerning contamination and fish well-being. In May 2018 a regulation for the allocation of new permits stated that it should only be in green production areas and the allocation is done by auction. The regulation included how much MAB one could distribute, who could participate in the auction, the minimum amount of volume, etc.

Fees for research and development in the fisheries and aquaculture industry were updated in regulation effective from September 2018. The funds should be managed by FHF[1] and utilized in research and development for the whole or parts of the fish and aquaculture industry (FOR-2018-09-05-1320, 2019).

The Traffic Light Model

To deal with the various challenges regarding fish health, welfare, and the environment, the government initiated the traffic light model. The arrangement separates the coastal line into 13 distinct production areas through the production area regulation. The purpose is to identify the scope of lice contamination imposed on wildlife in the vicinity of the production plants. Areas receive a status marker represented by the colors green, yellow, and red. Green indicates low risk and a less than 10% death rate among the wild salmon population. Yellow indicates medium risk and a death rate between 10-30% among the wild salmon population. Red indicates high risk and a more than 30% death rate among the wild salmon population. When assessing each area an Intertemporal Computable Equilibrium System is applied. An expert group makes their professional judgment based on a data set analyzed by their models, a control group will counsel the Ministry of Trade and Fisheries, and the Ministry will make its conclusion regarding status marker. The arrangement allows for increased production within green areas (Karlsen, 2016). Kvamme, research director at the contamination and disease department at IMR, concluded that the current models have a high prediction power based on validating field observations (Kvamme, 2017).

[1] The Norwegian Seafood Research Fund [Fiskeri- og havbruksnæringens forskningsfinansiering]

Development permits

The stated purpose of introducing development permits to the aquaculture industry is to stimulate sustainability, adaptation, and innovation and increased value creation within aquaculture. It aims to solve the environmental and area challenges the aquaculture is facing. The arrangement is delineated to technological production equipment and installations and does not comprise projects related to the development of new operational methods, vaccines, feed, etc. (Directorate of Fisheries, 2016). Some projects are deemed too big and risky for the industry to invest in without receiving financial aid from the government, and the arrangement should work as an incentive scheme to take on the extra risk that is inherent to these projects.

The application period was from 11.20.2015-11.17.2017. Within this period 104 applications were submitted, requesting a collective volume of 664,310 tons. The approved applications made up 57 permits, which amounted to 44,850 tons of biomass. The Directorate of Fisheries can grant conversion of development permits after the project period has ended provided that the criterium for the established project is fulfilled. The conversion recompense was set to NOK 10,000,000 in 2015 value. Considering the market value of a concession, getting a project approved could be very profitable in the long run. The price per ton from the concession auction held in June 2018 varied from NOK 132,000 to 252,000 where zone 1 yielded an average weighted price of NOK 132,000, zone 7-9 NOK 233,995, zone 10-13 NOK 163,796 (Viken, 2018) In the Directorate's guidelines for processing development permits applications, they operate with 780 tons per permit (Directorate of Fisheries, 2016). It is, therefore, safe to assume a single concession on average is 780 tons. With the average weighted prices and tons per concession assumption, a single concession is worth about NOK 93,456,000 in zone 1, NOK 182,515,721.1 in zone 7-9, and NOK 127,761,058.6 - in zone 10-13. This implies that five concessions meeting all criteria for conversion in zone 7-9, can spend NOK 826,578,605 on a failing R&D project without losing money. The arrangement gave a monetary incentive to develop a project with the hope of reaping the benefits that came with it.

3. The cost structure in aquaculture

Recent years have been a success story for the aquaculture industry, and the net income is higher than ever before. In this chapter, I will give a brief overview of the cost development from 2008 to the present date and a short explanation of each cost segment. The numbers are based on a representative number of companies with the total number of permits in the excerpt ranging from 619 to 743. In the chart depicted below, every cost category is kept constant to 2017 prices and adjusted to NOK100=2008 for comparison purposes.

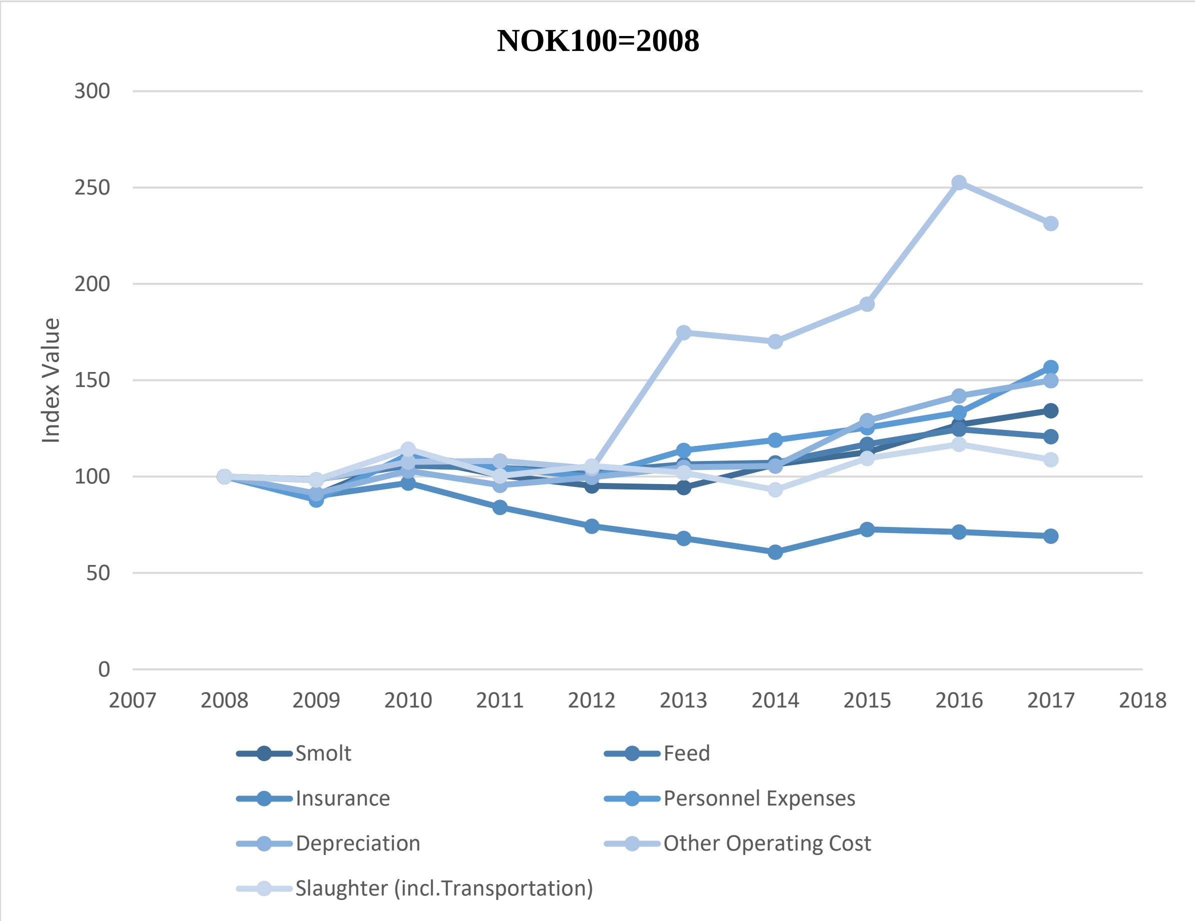

Figure 3-1 Cost per kg constant to 2017 prices

Data source: (Directorate of Fisheries, 2017)

From 2008 to 2017 smolt cost has increased by 37% in real value. The real cost of smolt have varied during the last ten years but have steadily increased over the last five years with a big leap from 2015 to 2016. Bigger smolt, different stocking strategies, new technologies, and regulations might be the causes of these changes. In the percentage of total production, smolt is down with 0.5% points for the period and makes up 9.4% of the total cost.

Over the 10-year period, feed cost has increased by 21% in real value. It has steadily accrued over time, except for 2014 to 2015 where the increase was 9% and from 2016 to 2017 when it went down by 3%. Marine ingredient prices have increased considerably in the respective period. Vegetable ingredients have also increased, but not to the same extent. This may be one of the reasons feed composition has changed over time in favor of more vegetable ingredients, to mitigate the effects of expensive marine ingredients. From 2000 to 2013 vegetable ingredients went from 35.4% to 70.8%. As a percentage of the total cost, the feed went down from 46% to 40% for the period.

Since 2008, personnel expenses have gone up with 57% in real value. Between 2008 and 2012 there were some fluctuations, but from 2012 and onwards personnel expenses have gone through a period of relative continuous growth. Lice treatments and preventative measures and lice associated tasks have become more frequent in facilities and are probably an important part of the changes I have seen. Personnel expenses make up 7.5% of all costs, which is an increase of 0.75% points.

The most significant increase in expenses is due to changes in Other Operating Costs. There has been some fluctuation in the period, however, the general trend is steady growth. From 2012 to 2013 the cost leaped 67.76% and from 2015 to 2016 there is a similar, but not to the same degree, upswing in expenses. Other operating costs cover a broad specter of different activities, and some of the main contributors to its rapid increase are activities like cleaner fish, lice net, snorkel cages, lice feed, and several preventative and treatment measures. Operations on facilities are to a larger extent executed by service companies which imply that expenses related to wages and depreciation lies hidden within this post. In 2017, Other Operating Costs makes up 29.6% of the total cost, which is an increase of 9.3% points from 2008.

The first half of this period was like the other segments, prone to fluctuations. Over 10 years, depreciation has increased by 50%. The growth is relatively smooth except for 2014 to 2015 when it increased by 22.8%. Transition to MAB, bigger cages, vessels, facilities, and regulations regarding equipment have driven the increase. The relative size of depreciation has been rather stable and has changed from 5% to 5.3%.

This is the only expense I choose to highlight that has declined during the period. It is down by 39% from 2008 to 2014 but has increased slightly towards 2017, so the total decline is 31%. Insurance cost is anticipated to increase, especially for red areas. This is due to the increased biological risk caused by lice, viruses, and treatment methods. Insurance makes up 0.35% of total cost and is halved during the period.

Slaughter cost has fluctuated throughout the whole period, but at the same time, it is the expense that has changed the least. From 2008 to 2017 it has increased by 9%. The industry has made investments in better equipment and technology, but the negative effect of this has been mitigated by higher output of slaughtered volume. As of 2017 slaughter makes up 8.5% of the total cost, a reduction of 2.5 percentage points since 2008.

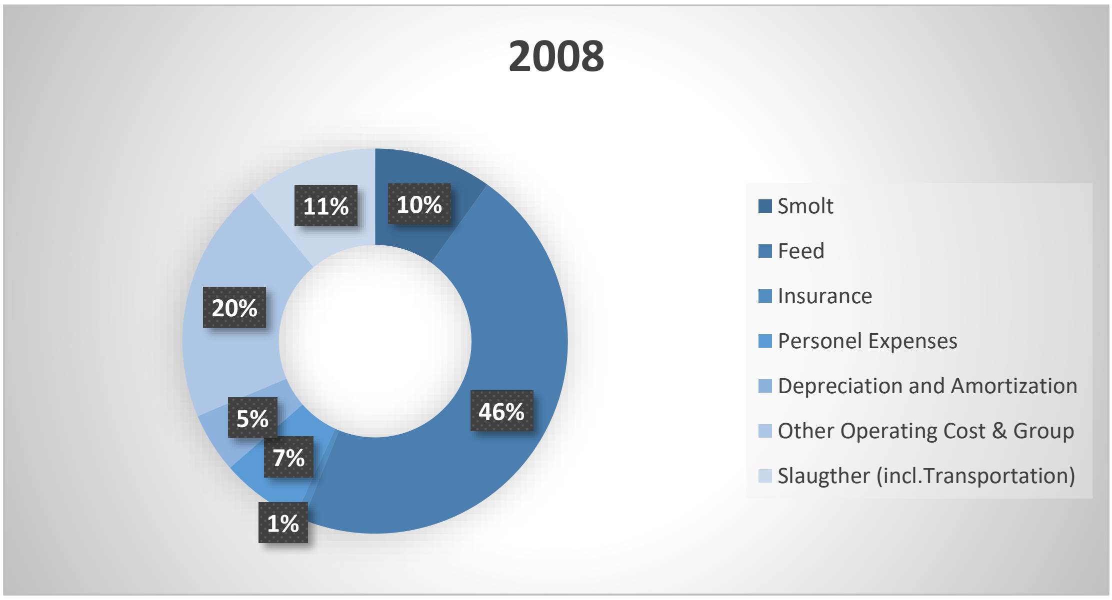

Figure 3-2 2008 Cost distribution

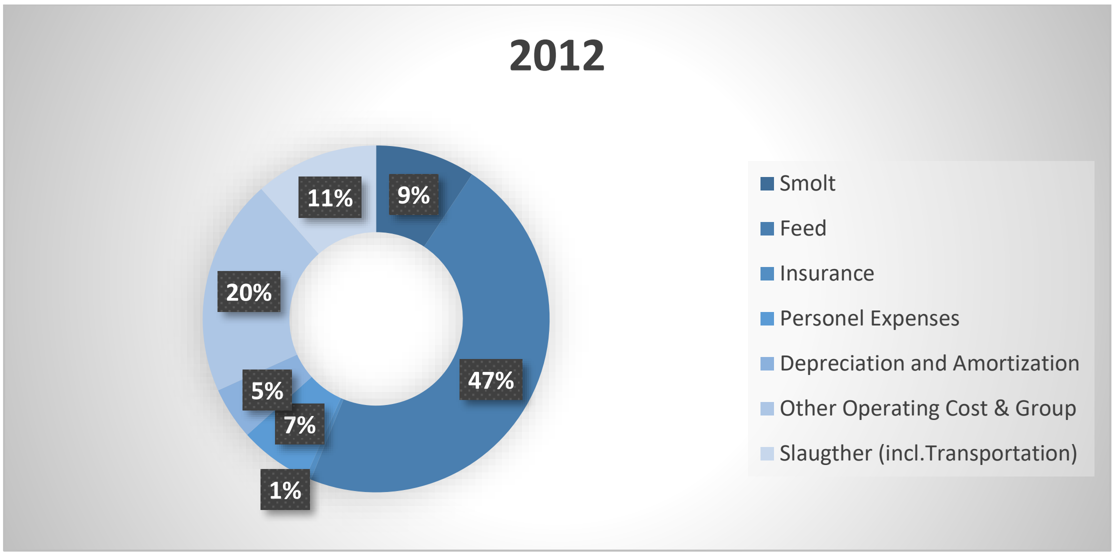

Figure 3-3 2012 Cost distribution

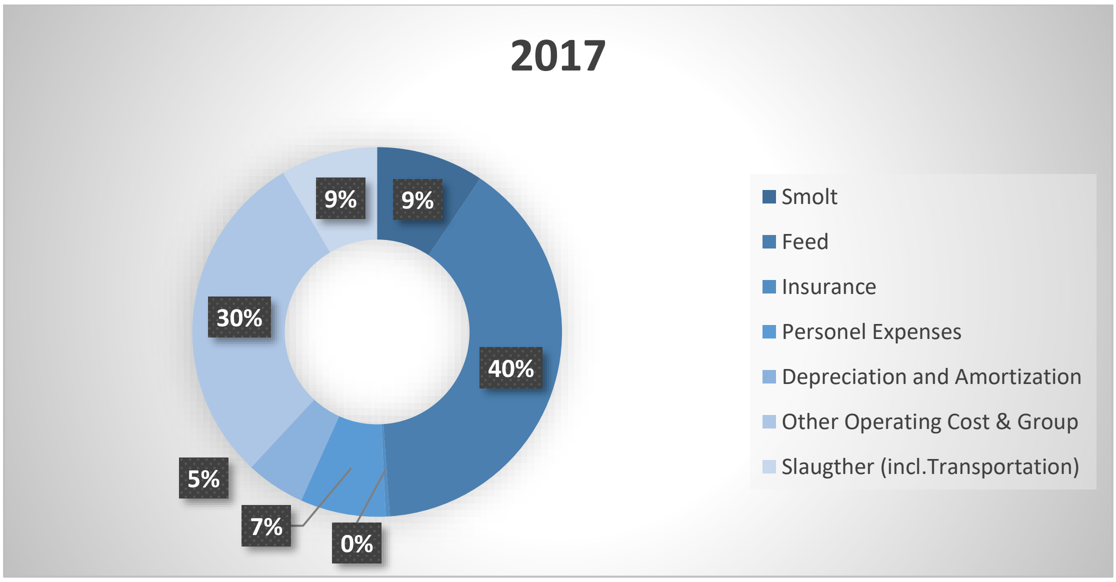

Figure 3-4 2017 Cost distribution

Data source: (Directorate of Fisheries, 2017)

An interesting observation from this break down is the development seen in other operating costs. This cost group contains many of the fish health-related expenses and is relevant when comparing to revenue development in the segments I present in a later chapter.

4. Atlantic salmon and its role for human beings

4.1 Biology of salmon

Atlantic salmon is an anadromous species, which means they begin their lives in freshwater, growing for some time before they roam to the sea. To migrate to the sea, the smoltification process must take place. This involves a physiological metamorphosis were the body becomes adapted to saltwater. They usually become sexually mature between the age of 1 and 3 years old (NOAA, 2019). When salmon is ready to spawn, they return to their natal stream, but periodically one can observe individuals deviate from their expected path (Høgåsen, 1999). In comparison with the Pacific salmon, Atlantic salmon can repeat their breeding cycle and do not die after spawning.

The salmon is easily recognizable on the streamlined body shape, the dark blue top, the shiny skin with black dots, and the fat fin, which lies in front of the tail fin. It is an *Osteichthyes* in the Salmonidae family, more commonly referred to as bony fish. In contrast to the *Chondrichthyes*, who are composed of cartilage, the *Osteichthyes* create their bone tissue. Like all *Osteichthyes* they possess gills, and this is their only means of respiration (Vøllestad, 2018).

Atlantic Salmon are a primitively ectothermic (cold-blooded) species, which means their internal source of heat is insignificant or very small in regulating body temperature. This is the preeminent reason why salmon convert energy in such an efficient manner. Comparing salmon to other land-based sources of protein, it becomes a paragon of energy and protein retention. The table below is retrieved from a master thesis conducted at the Norwegian University of Life Sciences in 2002, where the researcher evaluated protein and energy utilization in feed for lamb, pork, poultry and salmon and if using fishmeal and fish oil (FMFO) in fish feed could be considered a waste. The researcher concluded that salmon is much better than the other species and that using FMFO in fish feed is not a waste of resources. As seen from the figure below, Atlantic salmon outperforms lamb, pork, and poultry on all efficiency metrics.

	Lamb	**Pork**	**Poultry**	**Salmon**
Edible yield (percentage of living weight)	38.2%	52.1%	49.1%	68.3%
Protein retention	7%	20%	23%	31%
Gross energy retention	6%	12%	12%	21%
Feed conversion ratio	6.3	2.63	1.79	1.15

Figure 4-5 Yield, retention and conversion rates for farmed animals

(Bjørkli, 2002)

4.2 Health benefits

Numerous reports demonstrate plausible evidence of a positive health benefit for individuals substituting dietary fatty acids with unsaturated fat and polyunsaturated fatty acids from fish. Many prospective cohort studies investigating the causal effect of fish intake have concluded that fish reduce the risk of cardiovascular mortality, notably stroke and heart attack. Reduced blood pressure and improved insulin sensitivity were found to be the case during a randomized trial on young overweight adults. Fish consumption might also decrease the risk of impaired cognitive function, age-related macular degeneration, and type-2 diabetes. A systematic review and meta-analysis of 21 cohort studies found that proper intake of Omega-3 fatty acids correlated with a lower probability of getting breast cancer. Fish containing vitamin D have none or limited protective qualities against colorectal cancer (NNR, 2012). The cumulative epidemiological evidence leads to a general recommendation of increased fish and seafood consumption (NNR, 2012).

4.3 Health risks

European Food Safe Authority (EFSA) has performed epidemiological studies on humans with the support of animal testing and found a new upper limit for dioxins and dioxin-like PCBs. In a report from November 2018, they found it necessary to readjust the tolerable weekly intake (TWI) to seven times lower than previous recommendations (EFSA, 2018). Some of the negative effects were seen when consuming dioxins above TWI are decreased semen quality, the lower sex ratio of sons to daughters, higher levels of thyroid-stimulating hormone[2] in newborns, and developmental enamel defects on teeth (Thomsen, 2018). Even though dioxins have decreased during the last decade, a study from 2011 (Nøstbakken, 2014) found that consumption of Norwegian farmed Atlantic Salmon could be 1.3 kg with the previous TWI, but when adjusting for the new recommendations, the TWI would be around 0.2 kg.

4.4 Nutrition Development

Helsenorge is a public digital platform communicating information to inhabitants and patients in Norway. Their information regarding nutrition is delivered by The Directorate of Health. An Helsenorge article on nutrition advice identifies fish and seafood as an important source of the following nutrients; protein, omega3, vitamin D, vitamin B12, iodine, and selenium (The Norwegian Directorate of Health, 2018). Nevertheless, what has happened during the last three decades? The amount of FMFO has dropped from 90% to under 30% (Ytrestøyl T. A., 2014). The consequences of this reduction are that the concentration of the nutrients, except for protein, which is genetically predetermined, will go down. This negative effect can be adjusted for by supplementing the feed, but that is limited through regulations and the restriction on additive compounds. IMR is working on alternatives to vegetable feed, but it has yet to be implemented[3]. These developments should be worrisome for the industry. Why should people eat fish if the nutritional value compared to its substitute is lower? (Thonhaugen, 2016).

[2] Regulates growth rate, oxygen consumption, and basal metabolic rate

[3] Information retrieved during a phone interview conducted on 02.07.2019 with Rune Waagbo, Department Manager of Fish Nutrition at IMR

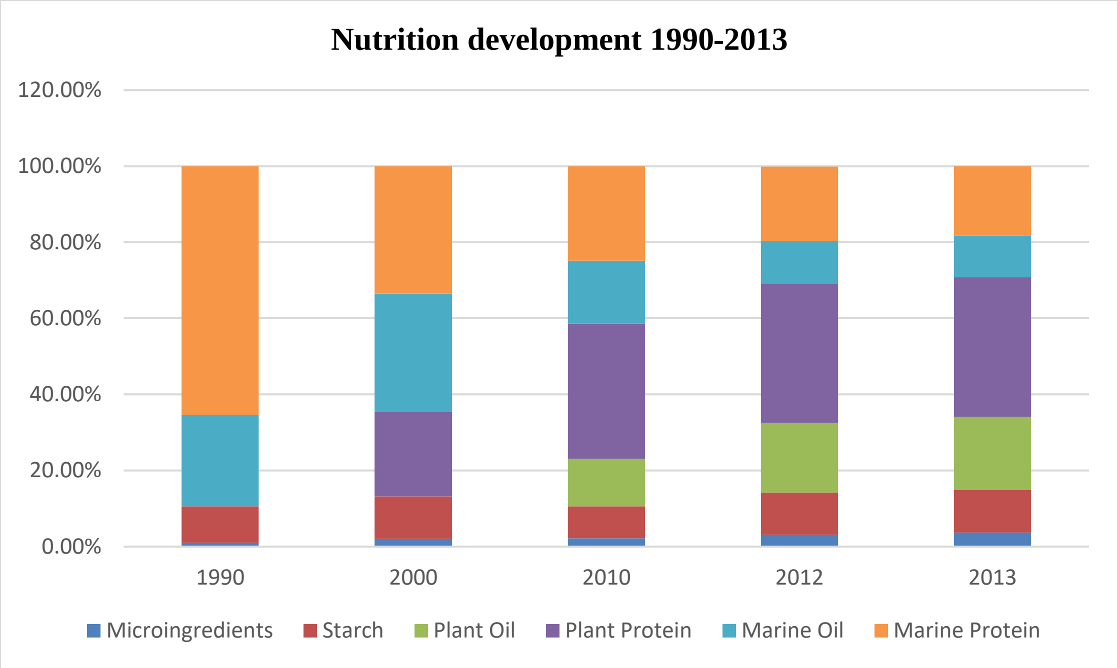

Figure 4-6 Nutritional development of feed for farmed salmon

(Ytrestøyl T. A., 2014)

4.5 Climate Considerations

In 2019, the current world population is at an estimated 7.7 billion people, expected to reach 9.8 billion in 2050, and 11.2 billion in 2100 (UN, 2017). The pressure caused by the increasing amount of human beings has shifted the demand for water, food, energy, and shelter and have altered Earth's biogeochemical systems (Costa-Pierce, 2016). Over the past 40 years, there has been a loss in agricultural land due to erosion and pollution. This loss phenomenon takes place at a higher rate than the replenishment of soil by natural processes (Hooke, 2012). Agriculture is the main factor driving the shortage of freshwater supply. It makes up 70% of the freshwater withdrawals in the world (Bruinsma, 2009). Evaluating the table below, it becomes obvious that salmon is a very good alternative to beef and pork but is almost equivalent to poultry. The metrics represented in the matrix below do not regard the loss of surface area and considering that land surface area is getting scarce, this should be evaluated. 12% of the globe's land surface is used in crop production (Bruinsma, 2009), but it would take less than 1% of ocean surface area to grow an equivalent amount of kelp (Costa-Pierce, 2016).

	Beef	**Pork**	**Poultry**	**Salmon**	**Reference**
Carbon footprint (kg CO_2e/kg edible part at slaughter/landing)	30	5.9	2.7	2.9	(Winther, 2009)
Energy use (MJ/kg edible part at slaughter/landing)	79	41	29	40	(Winther, 2009)
Freshwater use (liter H_20/kg edible part at slaughter/landing)	15,400	6,000	4,300	4,086*	(Mekonnen, 2010), (Auchterlonie, 2014)

Figure 4-7 Resource requirements for farmed animals

*This number relies on a certain amount of FMFO. In the SARF report, they estimate freshwater use to be 4,086 with an FMFO of 29.2%. Coincidentally, the Nofima report *"Resource utilization of Norwegian salmon farming in 2012 and 2013"* shows that feed content provided by BioMar, Ewos, and Skretting was 29.2% FMFO in 2013. Based on the phone interview with Rune Waagbo, the current trends and pressure on marine inputs would indicate an even lower share of FMFO today.

5. The theoretical and methodological framework

In this chapter, I will give an introduction to the theoretical framework, financial metrics, and the general method applied in this thesis. This is necessary to give a deeper understanding of its relevance and limitations. To get a qualitative understanding of variations in profitability within an industry, it can be useful to evaluate the different layers in a business environment. The outmost layer represents the macro environment and is best described by the PESTEL framework. The second layer represents the microenvironment and can be described best by Porter's five forces. For this thesis, the main focus will be on these two frameworks to give the best representation of which factors impact the industry.

The work throughout this thesis will rely on a mixture of quantitative and qualitative data. Some of my arguments build on findings regarding what technology is being developed, regulations imposed by the government, and societal advancement that cannot easily be quantified. I have provided statistics and charts throughout the thesis where I have deemed it necessary. The majority have been raw data retrieved from Proff Forvalt and The Directorate of Fisheries, but I have also utilized existing graphs produced by various reports. In The Directorate of Fisheries website, several datasets and summary statistics are available for the public. I have utilized these summary statistics to make visual representations of the data. The summary statistics are useful to see the general development within different parts of the analysis. At the end of the thesis, I present the result of a PMI-survey that I sent to many different companies engaged in aquaculture.

5.1 PESTEL – Macro analysis

The PESTEL analysis is a descriptive tool that can be utilized to evaluate the macro environment for a business, organization, or industry. One dissects the analysis into six factors, one for each letter in the name.

Political factors

The political factors are supposed to map the degree of stability and trust in society. The government can through laws and legislations make a foundation for wealth creation. Tax, fees, trade, and transparency is to a large extent controlled or influenced by the government and has a great impact on how businesses can operate within their industry.

Economical factors

This thesis will limit economic factors to industry-specific developments. It is worth noting that the general economic development, cycles, inflation, interest rates, currency, and fiscal policies will also affect the industry. When evaluating anomalies in economic development, I will try to explain this with events arising from within the industry.

Social factors

Under this component, I want to shed light on factors occurring within the aquaculture industry that can lead to negative attitudes among the consumers. How this, in turn, will affect the fish health segment both long term and short term is important to build a holistic perspective.

Technological factors

Technological development can contribute to different threats and opportunities through increased efficiency, better distribution, and changes regarding barriers of entry. Infrastructure facilitating research and development, innovation, and science will have an impact on businesses.

Environmental factors

Energy consumption, pollution, recycling is important factors to consider to assess the environmental impact of an industry. The fish health and cleaner fish industry is partly an answer for the aquaculture industry to combat pollution, among other factors. It is also important to evaluate the challenges and opportunities arising from a changing climate.

Legal factors

Through laws and regulations, the government exercises its power. There are various regulations specifically governing aquaculture, and the most important regulations affecting the industry are described in chapter 2.1. Nonetheless, legislation on the work environment, competition, export, and import will impact the industry.

5.2 Porter's five forces – industry analysis

Porter's five forces is a theoretical framework that aims at shedding light on the macro-environment within an industry, sector, or defined set of businesses. The forces are as follows:

1. **The threat of new entrants**
   - It is determined by barriers to entry such as fixed costs, patents, permits, start-up costs, regulations, etc. The sectors I will be analyzing consists primarily of businesses that require patents and permits to operate, but there will be examples where this is not the case. How easily a patent or/and a permit is obtained will also be important when estimating the threat of new entrants.
2. **The threat of substitutes**
   - Substitutes can be companies from different sectors solving the same problems but in a different manner. An example from the aquaculture industry is lasers killing lice as a substitute for cleaner fish. Their competitiveness is determined by their effectiveness. How much does one have to spend to get rid of one louse comparing lasers to cleaner fish?
3. **Bargaining power of customers and powers of suppliers**
   - It depends on the size of companies and the regulations imposed on them. Customers and suppliers are two sides of the same coin and can be seen as a holistic analysis of the vertical supply chain. A tool frequently used by The Norwegian Competition Authority is the Herfindahl-Hirschman Index. It gives a score to each company and the whole market by squaring the market size of each company and summing the individual companies to measure the total market score. This is not exercised without its drawbacks, because it is innately hard to define the true markets in many cases. The defined sector of smolt companies as seen in this thesis

would not trigger any response from the authorities by applying HHI[4]. If one considers the difficulty of transporting smolt over huge distances, it might be more realistic to define regions of smolt producers and their respective customers. In this thesis, I choose to emphasize with what relative ease a company can choose another customer or supplier, or if it is possible to vertically integrate.

4. **Competitive rivalry**
    - The degree of competition is determined by the number and size of companies competing for the same market concerning customers and suppliers. A market with a big number of companies with relatively small size differences has a high degree of competitiveness. When defining the market and evaluating the competitive rivalry, you will face the same challenges with regards to “correct market definition” as under the customer and supplier assessment.

Porter’s five forces is a neat tool for analyzing industries, revealing facts about the past and the present. However, it has some drawbacks as well, and I will highlight the ones relevant to this thesis. First of all, it is backward-looking. One way to deal with this is to focus on the trends and make arguments for why they will hold or fail. Second, it has been criticized for placing companies engaged in several industries into one defined sector. It is therefore important to show the reader where these weaknesses are in your thesis or paper. Lastly, how does one weigh the different forces? As with aquaculture, the threat of new entrants is controlled by the permits granted by the government, and it plays a small role in many of the sectors within aquaculture.

5.3 Financial analysis

5.3.1 Financial statements

All the financial statements provided are based on data retrieved from Proff Forvalt. In the process of determining how to select and group a company to a sector, I started by selecting several industry codes from the Brønnøysund Register Centre and downloaded a big list of companies. The first round consisted of controlling for relevancy by searching for the company name on the internet. Through a couple of more iterations of manually controlling every

[4] Unless many of the big companies were to merge into one, big company

company's website, I was confident I had found the relevant companies. The next step consisted of downloading financial statements and putting them together to obtain an industry financial statement. Ernst and Young have performed a similar task in *"The Norwegian Aquaculture Analysis"*, and my numbers are not far off from their work. A list of company names and organizational numbers will be provided in the appendix.

5.3.2 EBITDA – Earnings before interest tax depreciation and amortization

EBITDA is a financial metric used to measure earnings before interest, taxes, depreciation, and amortization. Its widespread application is due to its precise communication of corporate performance before accounting and financial deductions influence the metric. Because it omits certain factors, it allows for a more even-grounded comparison across industries. For this thesis, it is important to mention two of EBITDA's inadequacies. It ignores the costs of assets and working capital. A very capital intensive industry will look more profitable using EBITDA compared to an industry that is not as capital intensive (Berk & DeMarzo, 2016).

5.3.3 ROIC – Return on invested capital

ROIC is a financial metric used to measure return on invested capital. In the calculations I've utilized, ROIC equals EBIT multiplied with 1 minus tax percentage divided by the invested capital.

$$ROIC = \frac{EBIT(1-t)}{Invested\ Capital}$$

The invested capital used in the ROIC equation is as an average of the current and the previous period. This metric shows how much return a company or an industry gains on its invested capital. It is used as a benchmark for calculating the value of companies/industries and make comparisons between companies/industries (Berk & DeMarzo, 2016).

6. Fish health and welfare – status and trends

6.1 Overview

The first fish health report was published by the Norwegian Veterinary Institute in 2005 to shed light on the prevailing situation within Norwegian aquaculture. The aquaculture industry had become one of the biggest export industries in Norway, so the government deemed it important to examine and quantify diseases and other threats against farmed fish. In 2006, the Ministry of Fisheries and Coastal Affairs gave the Norwegian Veterinary Institute a mission to lead the development of a public system for monitoring the health- and disease situation for aquatic organisms. This tool would be applied to facilitate measures to prevent diseases, diagnose, and give correct treatment.

What started as a small report 15 years ago, has grown into a long and detailed document unveiling the potential diseases that can impact the aquaculture industry negatively. Virus, bacteria, fungus, and parasite diseases have been covered in great detail throughout the latest edition, and areas like fish wealth fare and cleaner fish are receiving increased attention. In this section, I intend to discuss the most economically impactful trends disclosed in this document. To what degree a disease, virus, parasite, etc. is deemed to have negative consequences will depend on a surfeit of different factors; how contagious it is, how long the organism can be infected before it is inedible, price of the vaccine or treatment method, cost variation concerning the two first factors, and several more variables. It could also have undesirable effects on fish welfare, and one should acutely assess the ethical challenges before implementing it. Throughout this chapter, I will refer to a questionnaire made by the Norwegian Veterinary Institute as a part of producing the fish health report. The questionnaire lays some of the groundwork of the report (The Norwegian Veterinary Institute, 2020). I will refer to it as the fish health questionnaire.

6.2 Fish Welfare

The Animal Welfare Act states that farmed fish shall live in an environment and be treated in such a way that they are ensured proper welfare throughout the life cycle. The act includes all species of fish living inside the enclosure. According to the report, there is still a long way to go before the fish receives treatment adequate to satisfy their welfare needs. The report defines fish welfare in great detail, but a short description would be *normal, biological function, individual perception of fear and pain, and the farmer should facilitate a normal life for the beings.* What I am interested in, is whether or not the conclusions or suggested measures can have a significant economic impact.

Uncertainty and ambiguity concerning laws and regulations governing health and welfare in aquaculture are making it harder to know if the current supervision is satisfying. The Institue of Marine Research and The Norwegian Veterinary Institue are working to develop and improve the laws and regulations. The Food Safety Authority is revising its guide for technology approval, and the objective is to mitigate vagueness surrounding procedures. If they can reduce ambiguity without causing drastic changes in routines and equipment requirements, this would undoubtedly make daily routines more predictable and bring positive long term consequences for costs and welfare. Executing this is a delicate process, and requires both practical and legal insight if it is to benefit the industry.

Hatcheries and producers of big smolt have started to utilize RAS technology. This technology has been put forward as a rig that will enable land-based farming. Unfortunately, the fish biologists contributing with feedback register a greater variation in the rate of death caused by insufficient water quality. One should expect a stricter regulation of water quality and further improvement regarding technology and surveillance routines.

Transport and slaughtering have the potential to cause a great deal of pain and damage to the fish. Slaughter vessels are being suggested as a solution, with the possibility of removing a lot of unnecessary suffering by simply removing the pain-inducing steps leading up to the slaughter. There are currently not many of these vessels in operation and it will require the current vessels to rebuild or be scrapped to make way for the new technology.

The report strongly indicates that the industry needs to shift its focus away from quantity toward welfare and health and concludes that that challenges regarding welfare are immense. There will most likely be economic complications because the conclusions could imply a paradigm shift for daily routines as well as existing technology. Remedy free delousing methods are probably the biggest source of misery and made up over 60 percent of the welfare feedback received by The Food Safety Authority. The report expresses great concern regarding the current delousing and measures will be initiated to deal with the precarious situation. If farmers cannot deal with the lice problem, they will be obliged by the traffic light system to reduce MAB. Areas struggling with a high density of lice could potentially face reductions of MAB if regulations on remedy free delousing methods become stricter.

6.3 Viruses

Virus infections contribute to the biggest losses when comparing contagious diseases, and the most prevalent diagnostics made by The Veterinary Institute are PD, Hearth and Skeletal Muscle Inflammation(HSMI), and Cardio Myopathy Syndrome(CMS). To allay the negative effects of viruses, the industry carries out preventative measures like vaccination, control areas, inspections, and water testing. There are more viruses mentioned in the report, but I have chosen to highlight the ones that have the most significant impact on the industry.

PD

PD is a grave disease causing severe damages in the pancreas and inflammation in the hearth- and skeletal muscles. To deter the infected areas, the government can demand facilities to slaughter or destroy fish whenever PD is detected. The PD regulation grants the government the possibility to impose vaccination against PD. From the 7th of July 2020, the obligation has been imposed on facilities between Romsdalen and Sømna in Nordland. In the fish health questionnaire, PD is put forward as the most important cause of bad growth and poor welfare. A study from 2015 found that a PD outbreak occurring nine months after sea transfer on an average salmon farm using 2013 sales prices, has an estimated cost of NOK 55.4 million (Pettersen, Rich, Jensen, & Aunsmo, 2015). Production can be reduced to 70% of sellable biomass, and production costs can increase by NOK 6 per kilogram in 2007 slaughter prices (Jansen, et al., 2015).

ISA

ISA is characterized by being present in the individual for a long time before one can observe any symptoms. The virus attacks gills, skin, and blood vessels. Outbreaks are strictly regulated and are followed by establishing control areas and inspection zones to abate the situation. However, the nature of the virus makes it hard to estimate the scope of its prevalence, and it is assumed that the unrecorded numbers are high. It is one of the few contaminants that can impede export to other countries, and countries can through a new EU law taking effect in 2021 demand no ISA when importing fish products. Together with PD, ISA can escalate into costly affairs considering the impacts of control areas, fighting, and loss of export. Facilities infected have to slaughter its total biomass, and this is very costly (Brun, et al., 2018). It is therefore quintessential to discover and fight the disease effectively.

6.1.5 CMS

CMS affects the heart and is very contagious. It is currently causing great losses for aquaculture. The scope of the economic impact is quite big because the industry lacks effective preventative measures, and the virus takes effect towards the end of the production cycle. The Veterinary Institute expresses concern regarding the development of the disease and highlights Hordaland as an example, where the situation has gotten to a bad state. They suspect that some of the reduction in reported cases is caused by increased utilization of private laboratories. There have not been many attempts at estimating the economic loss caused by CMS, but in 2007 it was estimated to be around NOK 200 million (Garseth, et al., 2017).

6.1.6 HSMI

HSMI affects the heart and skeletal muscles and the death rates vary quite a lot. The Veterinary Institute showed HSMI on 79 localities in 2019, but since the virus is not notifiable it is assumed to be a fraction of the entire picture. Individuals infected seem to be more prone to dying when deloused and treated in different ways. There is no public plan to fight the disease and no vaccine available on the market. Still, a more HSMI resistant QTL salmon have been developed, and methods for reducing loss amongst HSMI infected fish are avoiding stress. The data regarding this illness is quite vague, but the fish health services across the country consider it to be a big problem during the hatching and sea phase.

6.4 Parasite diseases

The report elaborates on several parasites, but I am just going to deal with the infamous salmon lice. It is worth mentioning that there is a considerable amount of parasites that have become problematic and have the potential to become problematic. The industry has experienced stand-alone cases of sea lice (*Caligus Elongatus*) where they have considered treatment necessary. None of them are close to being as time-consuming and resource-demanding as salmon lice.

Salmon Lice

Salmon lice is a parasitic crustacean feeding on fish skin, slime, and blood. A sufficient amount of salmon lice causes wounds and anemia, and if the concentration gets high enough, it is deadly. The maximum amount of lice allowed varies throughout the year; one limit during the spring, another during the rest of the year. In the fish health questionnaire, 12 of the respondents chose salmon lice as the most important cause of death and 54 chose damages after delousing (n=72). Respondents can also report immediate high death rates as a result of medical-free treatment methods[5].

[5] Heated water, flushing and/or brushing, and fresh water

In comparison to 2018, there is an increase in medical and non-medical treatments. Resistance against remedies is an increasing trend and the effects are getting less potency. Yet the number of treatments applying remedies went up from 2018 to 2019. The lion share of treatments is still medical free, where thermic treatments make up 59% of medical-free treatments. All the preventative measures today struggle with declining potency, selecting for more resistant lice, and pain-inducing methods for both salmon and cleaner fish. However, The Veterinary Institute started a project together with PHARMAQ and Sintef, aiming to develop a cost-efficient lice vaccine (Norwegian Veterinary Institute, 2020). Their greatest challenge so far is making a vaccine that is viable and cost-competitive to apply at an industrial scale. The project is set to be done by the end of 2020, but so far the results are promising and can be revolutionary for the industry if they can come up with a useful product. Partly or fully closed pens, offshore facilities, and salmon farmed at certain depths are new ways of operating in which the industry has high hopes. Yet, until vaccines and new operating methods are fully implemented, the industry seems to be fighting a battle where the salmon lice are winning.

6.5 Other health-related issues

Other health-related issues, two problems have been placed in the top-5 category of increasing concern. I will elaborate on these to matters, and shed light on the algae outbreak of 2019, causing mass-death in two northern regions.

Gill problems

The data from the questionnaire suggests that operculum[6] shortening is an important factor in reducing welfare, growth, and increasing death rate. There is currently insufficient data from The Veterinary Institute, no vaccines, and no effective treatment methods. All this considered, it is quite worrisome for the industry that the experts consider complex gill disease to be the number one increasing health problem.

[6] Operculum is a bone that covers the gills of *osteichthyes*

Nephrocalcinosis

This health-related issue is considered, according to the questionnaire, to be the number one cause of increasing health-problems. It is considered a production disorder and may cause reduced growth. Because the condition is closely linked to the balance between water consumption and biomass, nephrocalcinosis is considered an important welfare-indicator and its presence is an indicator of other negative welfare effects. Facilities can fight back the disease by optimizing water quality and make a feed that promotes optimal health at the fish given stage of development.

Algae outbreak

In May and June of 2019, the northern regions of Norway experienced an alga outbreak causing approximately 8 million individual salmon with an estimated value of NOK 2.1 billion to die. Chile went through a similar situation in 2016, but with far worse consequences wiping out an estimated 24 million salmon (Kearns, 2016). This phenomenon does not seem to be a recurrent event, but it is worth mentioning because when the damage is done, it can have devastating consequences. Experience from the situation in 2019 shows that the producers most likely saved many individuals by moving fish to less exposed locations. A contingency plan for future events should be in place to avoid damages of similar magnitude to the unfortunate events of 2016 and 2019.

6.6 Cleaner Fish

Bacteria and virus affecting lump roe is generally not a problem for salmon, but it inflicts a great deal of suffering on the cleaner fish. Parasites, on the other hand, affects both cleaner fish and salmon, where the most frequent parasite is the one causing amoeba gill disease(*Paramoeba perurans*). Sea louse is also transferable from cleaner fish to salmon.

The questionnaire indicates great challenges with death rates of cleaner fish regarding infections, handling, tending, wounds, and emaciating. This is especially after the fish has been released into the pens, and the lum roe seems to be bearing the brunt of the problems. Many respondents believe that the regulations surrounding cleaner fish have to become clearer, based on knowledge, and stricter to make sure that welfare is preserved for the cleaner fish. Despite the increased focus on cleaner fish welfare, the development is going in the wrong direction. This should be quite worrisome for the industry because cleaner fish is a vital part of minimizing the harmful effects of salmon lice. Stricter regulations could lead to a higher lice count and in turn, reduced biomass. It could also require the producers to implement systems and routines, catering to the needs of cleaner fish, making the real cost of the cleaner fish increase.

6.7 Final remarks

Health and welfare-related problems are highly intertwined with one another and solving one could have the potential to increase another. The most outstanding example is related to cleaner fish. If the producers were to stop using cleaner fish, there would more than likely be a dramatic increase in salmon lice concentration. This would lead to more suffering for salmon and a lower amount produced. However, by persisting in keeping the cleaner fish, one just shifts some of the problems to another organism. The report indicates stricter regulations regarding welfare, treatment, and vaccination. Combined with an increased frequency of parasites, viruses, and bacteria, better ways of measuring and supervising, they will demand higher expenditures and potentially fewer individuals bred.

7. Strategic analysis

7.1 Macro analysis of fish health

The fish health sector includes a wide gamut of different companies. When evaluating the EBIT margin break-down later on, the numbers will be an aggregated representation of companies involved in vaccination, pharmaceuticals, medicine feed, applied research, antifouling, biotechnology, contamination safety products, tarpaulin treatments, health controls, diagnostics, sanitation appliances, histopathology screening[7], current measurement, and agglutination tests[8].

Political and Legal

Accredited laboratories have increased demands regarding analysis and monthly reports which indicates a higher workload going forward (The Norwegian Government, 2017). The food producer is responsible for food safety and one of the basic responsibilities is conducting hazard analysis and critical control point (HACCP) which includes several of the companies in my dataset. All remedies used in the treatment against lice need approval from The Norwegian Medicines Agency (SLV). IMR is imposed by The Norwegian Food Safety Authority to surveil salmon lice on wild salmon (The Ministry of Trade, Industry, and Fisheries, 2014). New demands regarding bathing remedies restricting usage give the incentive to shift treatment methods for facilities located near spawning grounds or in areas were well boats are scarce (The Ministry of Trade, Industry, and Fisheries, 2019).

Economic

Pharmaq opened a new factory to supply the market with vaccines in the years to come. They expect the market to grow substantially in the following years (Olsen, 2017). New methods for delousing has reduced the demand for anesthesia, stated by Scan Aqua and the graph displaying remedy usage (Olsen, 2019). Delousing, CMS, PD, SAV, ISA and AGD is still a big source of

[7] Study of changes in muscle tissue caused by disease

[8] Indentifies bacteries in the blood of an individual

unwanted expenses for the industry and a big potential for fish health companies (Hjeltnes, et al., 2018)

Social

Reduced fish health and well being are potential barriers for growth in Norwegian aquaculture, which has possibly led to an increased interest for specialized veterinarians (Bjørshol, Hellberg, & Dalum, 2019). A recent study conducted by IMR may indicate severe pain during treatment involving temperature changes to the levels inflicted by the current mechanical methods (Grindheim, 2019). In an article from IMR, research director Tore Kristiansen gives an account of reasons to care about fish well being, how to measure it, and how to improve it (Kristiansen, 2019).

Technological and Environmental

Experiments with Protec, a special feed patent held by Skretting, shows promising results for improved fish health and well being (Salmonexpert, 2019). Identifying new DNA sequences making it possible to breed fish immune to viruses, could yield benefitting results for aquaculture breeders (Fraslin, et al., 2019). X-ray photos reveal salmon's weaknesses and deformation and have become an important tool in the process of learning more about the species (Hommedal, 2019). Chemical treatments against salmon lice have dropped drastically and have not been lower since 2005. Anesthesia has had a downward trend from 2015, but surface treatment sales were very high in 2016 and 2017 much due to the approval of formaldehyde (The Norwegian Institute of Public Health, 2019). PatoGen AS wants to use data to make predictions for optimal fish health (Saue O. A., 2018). This could improve diagnostics and reduce the loss of biomass.

7.2 Macro analysis of cleaner fish

Political factors

In 2014, The Minister of Fisheries implemented three measures to deal with the pharmaceutical practice and the increased resistance among salmon lice (The Government, 2014). Through the food safety authority, the government continuously works to evaluate and develop plans to improve fish well-being (The Norwegian Food Safety Authority, 2017). The food safety authority will inspect several conditions regarding agents involved in cleaner fish activities. This includes boat registration, animal treatment, and personnel competence (The Norwegian Food Safety Authority, 2019).

Social

Trygve T Poppe, a veterinarian at the faculty of veterinary medicine, goes far in criticizing the cleaner fish conditions. According to him, today's standard is far below what one should expect, and the cleaner fish is being sent to the facilities as a martyr (Poppe, 2018). Given enough attention in the media, this could emerge as a pressure point for cleaner fish producers (Poppe, 2018). A study conducted by IMR found that lump roe will not be able to swim in currents stronger than 34 centimeters per second, metabolic capacity is 40% of the salmon, and when temperatures rise above 18 degrees celsius, the death rate goes up (Jakobsen, 2018). According to the research, the typical currents are 30 centimeters per second often rising to levels between 60 and 70 centimeters per second. The study concludes that these are the characteristics of a species living at the bottom of the sea, and would support the notion that the lump roe is unfit for the conditions on the aquaculture facilities.

Environmental and Technological

Hideouts for cleaner fish is a necessity to make sure their well-being is safeguarded. Technological progress in this area is gained through increased safety, less volume, fewer waste products, and more efficient cleaning (Soltveit, 2018). Sintef is experimenting with different types of feed and bacterial quality of water, which will increase cleaner fish survivability and growth rate (Sunde, 2019). Recycling cleaner fish to the next generation of salmon is highly wanted. The potential gains are a lower burden on the environment and reduced cost for salmon breeders. VKM[9] (Vitenskapskomiteen for mat og miljø, in Norwegian) concludes that amoebic gill disease is the only known disease that is suspected to be transferred from cleaner fish to salmon (Basic, 2017). VKM has evaluated and identified species that are relevant for import and use in aquaculture. In this evaluation, they uncovered the external effects of genetic changes, the spread of species outside their natural habitat and sickness and parasites distribution across geographical areas. The most important results were: *"Imports of purified fish for use in Norwegian farms expose Norwegian biodiversity to moderate risk. Imports of purified fish can lead to genetic changes in local populations, that the species establishes beyond where they naturally belong, the spread of infectious agents and that foreign organisms are included in the purchase."* (The Norwegian Scientific Committee for Food and Environment, 2019).

Legal

Changes in several regulations that could infer an increase in cost for cleaner fish producers. More bureaucracy, stricter demands on transportation, and facilities are potential challenges for this grouping (The Norwegian Government, 2017). In the consultation paper *" Proposal to amend regulations on aquaculture for adaptation to transport, storage, use, and production of purified fish»*, MOWI deemed the changes good and necessary (Marine Harvest ASA, 2017). To increase well-being, cleaner fish have gained equal status concerning health and well-being as salmon, permits for breeding will now entangle cleaner fish and governmental requirements regarding the registration of stocking and withdrawal of living fish and feed usages and feed type (The Norwegian Government, 2019).

[9] The Norwegian Scientific Committee for Food and Environment

7.3 Industry analysis of fish health

The threat of new entrants

The top five companies made up 73% percent of the revenue in 2017, and the concentration has been declining since 2011 when they had 86% of all revenue. The market concentration in this segment is heavily influenced by two exogenous factors, virus outbreak and patenting. If a business has obtained a patent on a vaccine against a virus, they effectively become a monopolist. E.g. MSD Animal Health had a monopoly on the PD vaccine (Armstrong, 2015), but after Pharmaq and Elanco were granted access to the market, MSD went from being a monopolist to controlling 21% of the market (Saue O. A., 2018). Personnel expenses have had a remarkable increase as a percentage of revenue during the period of observation. The biggest increase was from 2010 to 2011 and has since then fluctuated before reaching its all-time high in 2017. Fish health does not seem to be a capital intensive industry based on the fact that one observes similar profitability across the entire segment. Maarten Aerts, a chief engineer at Norwegian Accreditation, claims that most companies applying for accreditation get approval. He believes that this is due to the high representation of qualified individuals working for the applicants[10]. Achieving the accreditation is not a practical barrier of entry, but rather the acquiring of adequate expertise. The development in market concentration and low capital intensity goes in favor of low barriers of entry, but changes in personnel expenses, the necessity of qualified personnel, and the two aforementioned exogenous factors contribute to increasing the barriers of entry.

Threat of substitutes

Cleaner fish is a double-edged sword. It is a substitute for treatment, but a possibility in terms of vaccination, because the cleaner fish needs vaccination. Some fish health companies have even specialized in cleaner fish vaccination. Assuming the revenue generated from an increased number of individuals in need of vaccination is higher than the revenue loss from less medical treatment, a shift towards cleaner fish would be positive for the industry. A one-dimensional economic evaluation of cleaner fish introduction to the market would predict that producers would consume one extra cleaner fish up until the next cleaner fish is marginally more

[10] Phone interview conducted 04.09.2019 with Marten Aerts, Accreditaion Manager at Norwegian Accreditation

expensive than performing a treatment. On the other hand, one has to consider factors like government regulations regarding lice and number of treatments, this picture becomes very distorted and hard to measure.

Gene selection is a highly viable substitute for the fish health segment. Accomplishing immunity against viruses, bacterias, or developing a gene that repels salmon lice has the potential to stir up the entire industry.

The potential new markets that cleaner fish brings, could mitigate some of the negative effects of less treatment. Gene selection might prove itself to be viable and is something the aquaculture industry should pay close attention to. However, it is still quite uncertain what the limits are.

Bargaining power of customers

Patenting and government regulations can create situations where the customers (salmon producers) are deprived of many alternative opportunities and have to buy medication from a monopolist to treat infected fish. If you remove patenting from the equation, one suddenly has a market with many competitors and several options for the customers. The bargaining power of the customers seems to depend on whether they are facing a monopolist or not. Product differentiation is minimal between companies, and for all intents and purposes, fish health companies are offering homogenous products.

Bargaining power of suppliers

The cost of materials and personnel expenses has gone through some drastic changes since 2010. One can observe from the EBIT margin break down that the development of these costs has been rather slow compared to revenue. Further assumptions made about the cost of materials are that they are acquired in a market characterized by free competition. The trend towards higher personnel expenses and lower cost of materials are smoothly distributed over the entire period. Following the development of personnel expenses and decreased prescription possibilities (Soltveit, 2018), high bargaining power among suppliers of labor might be present.

However, the increased personnel expenses could be due to a general high wage development and more labor-intensive challenges, which makes it hard to conclude.

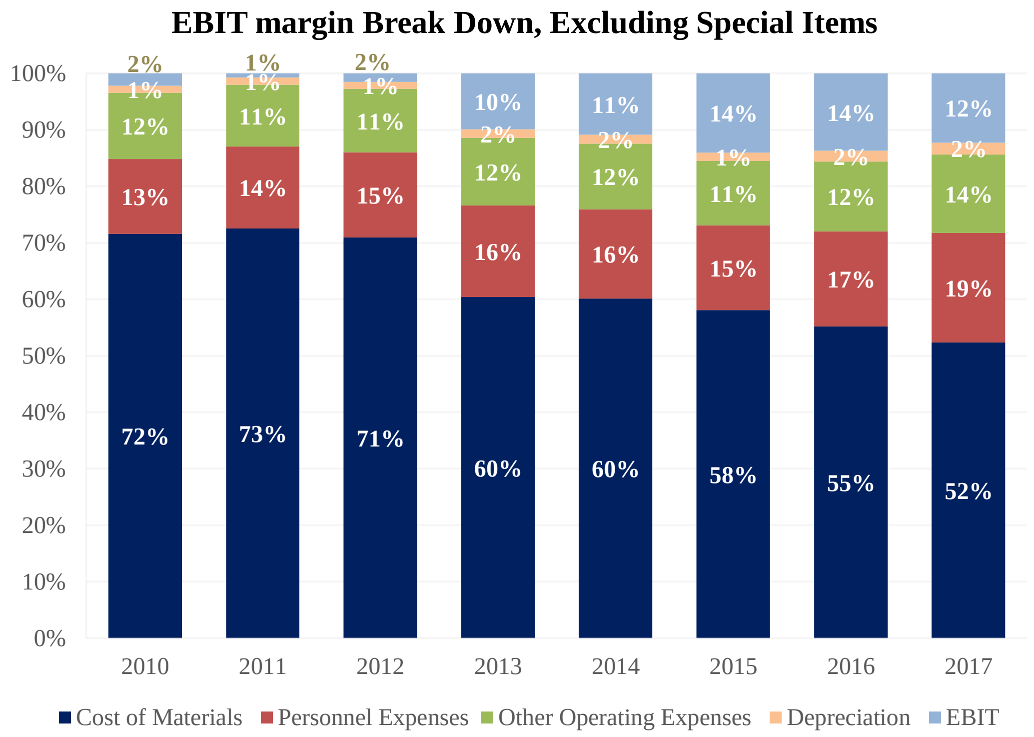

Figure 7-8 EBIT margin Break Down Fish Health

Competitive rivalry

The aquaculture industry relies on companies to conduct research and experiments to develop new products for vaccination and treatment. I interpret the patenting arrangement within this industry to work as an incentive system for businesses to expand and make progress within their field. When firms obtain a patent, it should be regulated in such a way that the expected income from the start of development to the patent has expired would be higher than not starting development. This structure ensures continuous research and development for products that can solve new or existing problems in a better and more efficient manner. Depending on how the demand curve looks down the value chain, the final consumer could end up paying the entire price or it could distribute itself across the value chain.

Judging the competitive rivalry, patenting and recent development in personnel expenses seem to be the most limiting factors on competitiveness. It is important to note that it is hard to make a concrete evaluation of competitiveness because many of the companies are not in direct competition with each other[11]. My evaluation has focused on companies delivering vaccines and treatments, but many companies have their income from other activities as well.

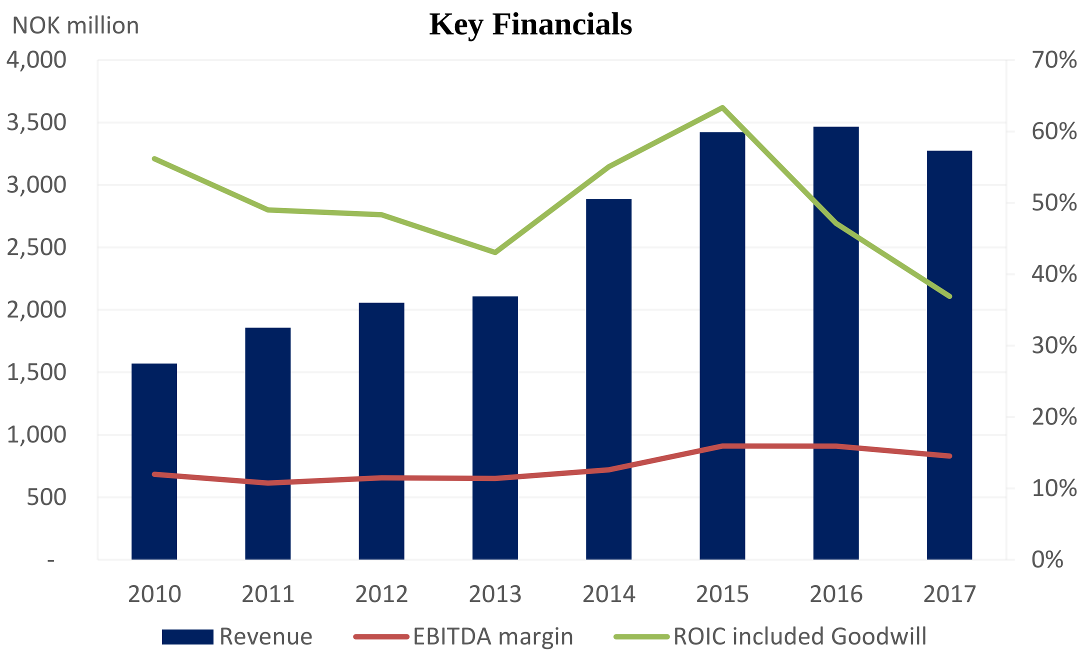

Figure 7-9 Key Financials Fish Health

[11] See introduction of the segment to get an overview of products and services provided

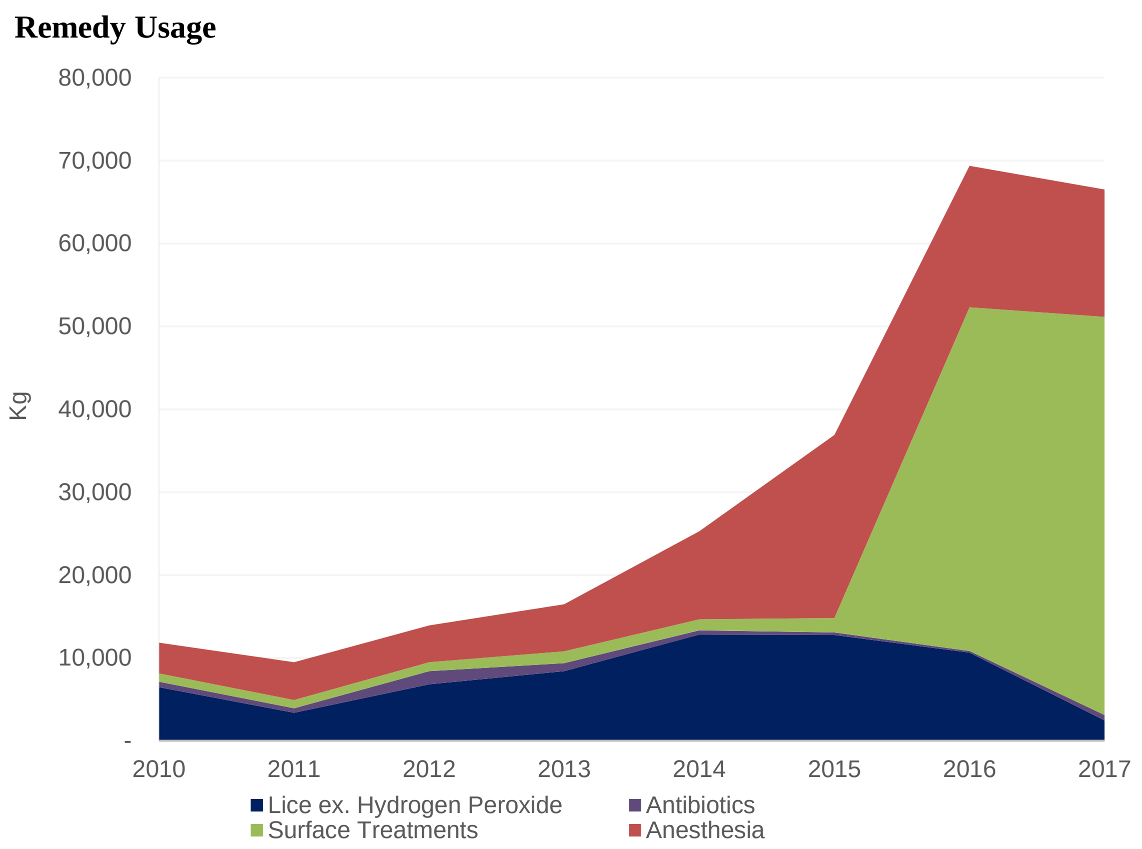

Figure 7-10 Remedy usage in Norwegian Aquaculture

Data source: (The Norwegian Institute of Public Health, 2019)

Concluding remarks

The revenue growth between 2010 and 2015 has been formidable yet turning into a decline from 2016 to 2017. ROIC spiked in 2015 due to a relatively bigger increase in EBIT than Invested Capital. In 2017 the ROIC is back to levels for the 2010-2013 period because EBIT went down after 2015 but Invested Capital has kept growing. For this period, businesses within this segment allocated their capital very efficiently. In comparison to industry averages in the United States, these numbers place fish health in Norway at the top (Damodaran, 2020). The figure below shows the top fifteen industries in the US as measured by ROIC.

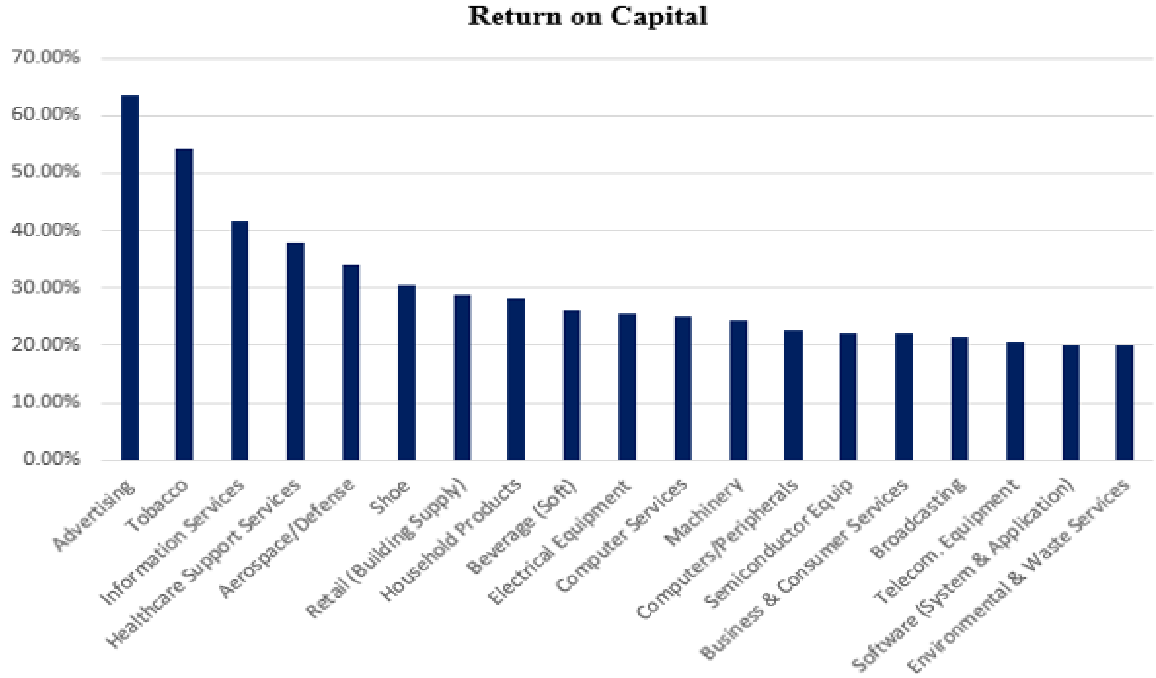

Figure 7-11 ROIC top fifteen industries

Appraising this segment by making a vast generalization becomes futile when evaluating the variety of goods and services into consideration. Without implying anything about the revenue turnaround in 2017, the risk for future revenue loss is likely to be present due to the advancements of substitutes. And one can observe from the figure below ROIC peaks when remedy usage goes up, which indicates that this segment depends on remedy usage to a certain degree.

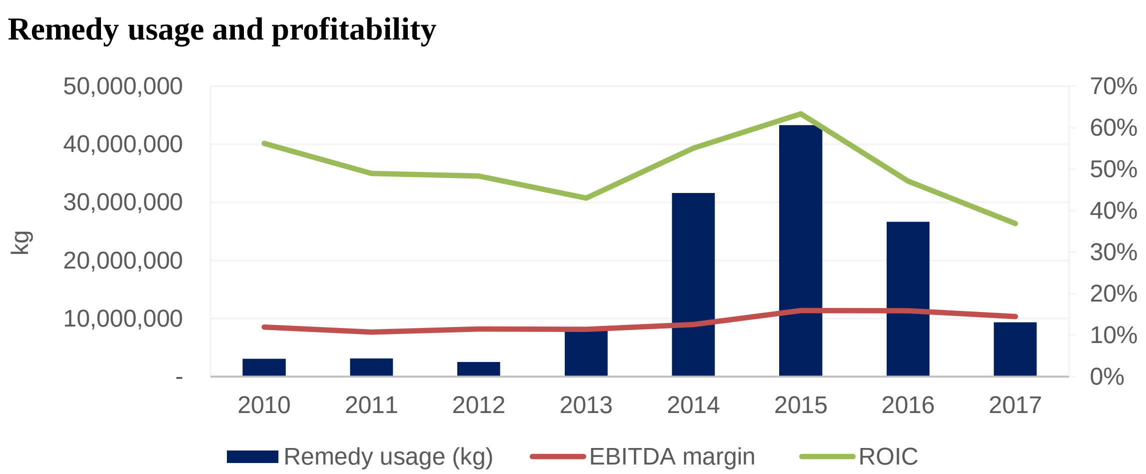

Figure 7-12 Remedy Usage and profitability

7.4 Industry analysis of cleaner fish

The threat of New Entrants

Potential intruders are agents who can obtain a concession for cleaner fish breeding, or capture wild cleaner fish while following best practice concerning industry standards.

During the last years, the number of breeders within this segment has increased considerably. High demand for alternative lice treatments has made this segment very profitable. According to Namdal Rensefisk, the economy of scale make their production facility less exposed to risk and capable of delivering a high quantity of fish with a substantial margin (Berge, 2016). In the cleaner fish industry, Tomma Rensefisk, a relatively small company with sum assets of NOK 30 million and an EBIT of NOK 3.4 million One can see that size is not necessary to earn a profit in this business. These two businesses are among the best earners in the industry for 2017, and they help to illustrate that capital requirements are not necessarily a barrier to entry in this group.

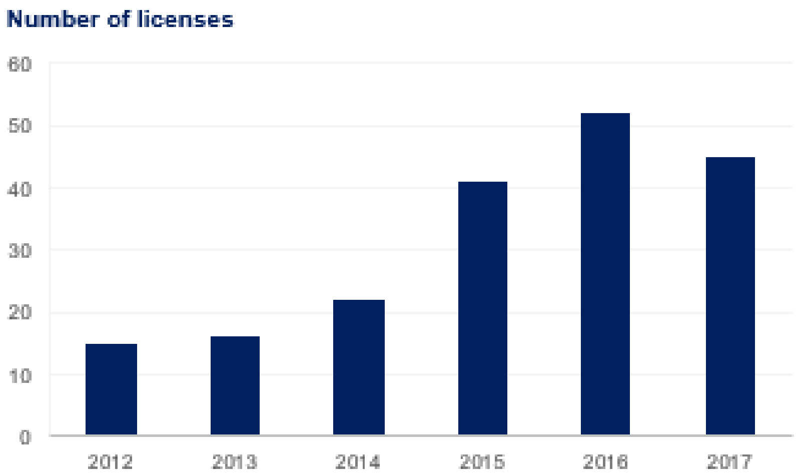

Figure 7-13 Number of licenses for cleaner fish

Data source: (Directorate of Fisheries, 2019)

From 2012 to 2016 the number of licenses for cleaner fish breeding went up, but the trend has retracted. The status change of cleaner fish and stricter supervisory guidance will contribute to making it harder to obtain a permit. I do not consider the capital required to start up as a significant barrier to entry, and with today’s interest rates, capital is cheap. Overall, cleaner fish have relatively low barriers to entry, but tougher demands from the state can make it harder for newcomers.

Threat of Substitutes

Substitutes for this segment is any form of lice treatment or action that can replace the necessity of cleaner fish. This implicates special feed, genomic selection, land-based farming, or other technology that gets rid of the lice in an equally, effective manner.

The threat of substitutes will rely on price, effectiveness, and regulations restricting them. Laser technology is, in theory, one of the more prominent substitutes. Cleaner fish has been eating a lot of colored salmon lice the last couple of years, and this has resulted in a selective breeding process favoring transparent lice. Cleaner fish does not eat the transparent lice, and if this selection process continues, it would be bad news for cleaner fish breeders (Soltveit, 2018). Stingray Marine Solutions does not worry, and they think it is good news for their technology (Fenstad, 2018). Nofima and The Research Council of Norway are currently positive to the potential of laser treatment, but further projects remain to document its feasibility (Stensvold, 2017). In a study conducted by AquaGen in 2017 genomic selection for lice reduced infestations with 40-55% (Aquagen, 2017). Each generation going through the selection process yields a reduction in infestations by 20-25%, and the future potential inspires optimism. Land-based farming will take place in a highly controlled environment, and you will be limited to viruses and parasites existing in the water that is being pumped into the facilities. This solution has the potential to solve a lot of health issues, and cleaner fish would no longer be in demand.

Feed companies play an essential role in constituting a product that can foster healthy and nutritious salmon. Lately, they have gained a role countering lice delivering special pellets containing remedies preventing and treating against the parasite. The biggest challenge for feed producers going forward relates to the input factors of feed and, and how this affects fish health and welfare and the nutritional value of the product. The institute of marine research is working on several alternatives (Jakobsen, 2019) to decrease the high amount of plant products as mentioned in chapter 4.4. Going far down in the value chain and utilize easy, accessible energy will be important. Research on insect meal shows promising results for fish health and taste (Nagelsen, 2018), but it has to be an economically viable option before the feed producers are going to apply it.

Bargaining Power of Buyers

Cleaner fish is a homogenous product, choosing a competitor would not change the product you obtain. However, there might be an increased risk of spreading disease when buying wild-caught cleaner fish from an external region (Rueness, et al., 2019). The current substitutes are limited through regulations or being at an early phase. Considering the recent year's development in the number of cleaner fish released, the demand has skyrocketed. The value per fish has increased every year since 2006, except for 2013 when the whole industry took a downturn. From 2016 to 2017, the number of fish increased with 46% and in the same period, the value per fish increased by 8%. Taking these numbers into consideration, there seems to be a shortage of cleaner fish supply. The current status is relatively low bargaining power, but this can easily change if the number of agents within this segment continues to increase and the substitutes prove worthy to the end-customer.

	Floating prices				Constant 2017 prices		
	000's	000's			000's	000's	
	Number	Value NOK	Value per fish		Number	Value NOK	Value per fish
1998	2,369	9,231	3.90	1998	2,369	13,622	5.75
1999	2,619	10,862	4.15	1999	2,619	15,659	5.98
2000	1,876	8,147	4.34	2000	1,876	11,394	6.07
2001	2,321	10,425	4.49	2001	2,321	14,154	6.10
2002	1,573	6,447	4.10	2002	1,573	8,641	5.49
2003	1,539	7,947	5.16	2003	1,539	10,393	6.75
2004	1,134	6,058	5.34	2004	1,134	7,886	6.95
2005	781	4,268	5.47	2005	781	5,472	7.01
2006	682	2,240	3.28	2006	682	2,807	4.12
2007	1,564	7,499	4.79	2007	1,564	9,330	5.97
2008	1,696	8,627	5.09	2008	1,696	10,344	6.10
2009	4,883	31,286	6.41	2009	4,883	36,705	7.52
2010	10,976	90,606	8.25	2010	10,976	103,792	9.46
2011	10,639	110,327	10.37	2011	10,639	124,780	11.73
2012	13,903	150,598	10.83	2012	13,903	169,150	12.17
2013	16,206	161,812	9.98	2013	16,206	177,973	10.98
2014	24,467	274,285	11.21	2014	24,467	295,634	12.08
2015	26,409	370,704	14.04	2015	26,409	391,071	14.81
2016	37,359	652,351	17.46	2016	37,359	664,615	17.79
2017	54,575	1,048,532	19.21	2017	54,575	1,048,532	19.21

Figure 7-14 Value per cleaner fish

Data source: (Directorate of Fisheries, 2019)

Bargaining Power of Suppliers

The requirements to start cleaner fish breeding are simply put a permit, material, transportation, labor, and broodfish. I assume that technological solutions, equipment, labor, and transport required to construct and operate the facilities, are supplied by more than a few numbers of businesses and people. In other words, there is a lot of competition and they do not have much bargaining power. The broodfish market for lump roe, on the other hand, is almost a monopoly, where Skjerneset Fisk AS delivers 90% of every lump roe eggs that are being hatched in Norway. Their operating income in 2017 was NOK 9.45 million, which makes up under 5% of the cost of material for the cleaner fish industry. A change in broodfish prices would not have a great impact on costs. All things considered, the bargaining power of suppliers is relatively low.

Competitive rivalry

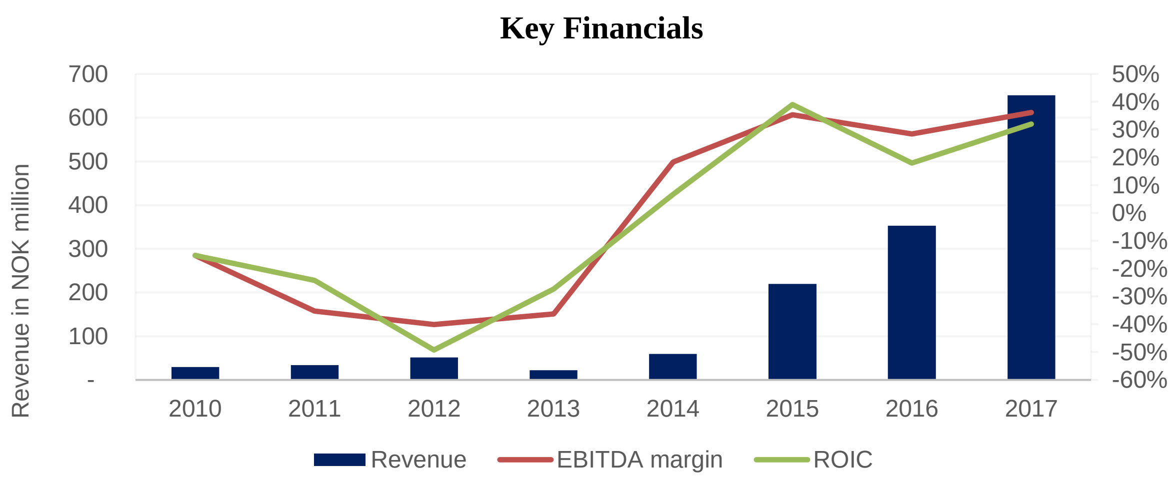

Figure 7-15 Key Financials Cleaner Fish

The number of businesses has increased remarkably since 2013, and one can see how the segment was virtually non-existing in 2014. However, the demand for cleaner fish seems to outweigh this growth. Comparing the development of fish released against the development at price, it becomes clear that production cannot satisfy the demand. As of today, cleaner fish might be the best preventative measure against salmon lice, and it might have been a successful implementation as shown in the development of cleaner fish and lice.

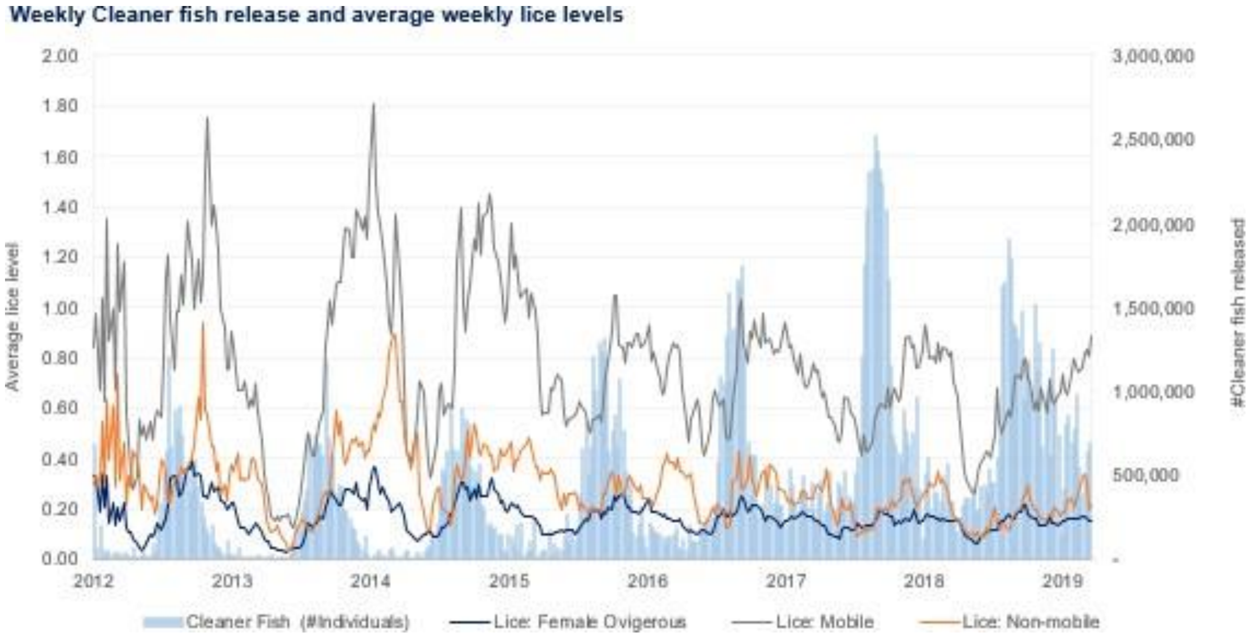

Figure 7-16 Weekly cleaner fish release and average weekly lice levels

Data source: (Directorate of Fisheries, 2019)

The businesses in my dataset have great profitability across different amounts of capital invested. It does not seem to be a capital intensive industry at the moment, but companies have already started to invest in big industrial production (Berge, 2016). The graph below illustrates the geographical spread of producers and cleaner fish. The series correlation is 0.8, where Hordaland and Møre & Romsdal seem to be the outliers.

All these factors combined go in favor of a relatively low competitive rivalry.

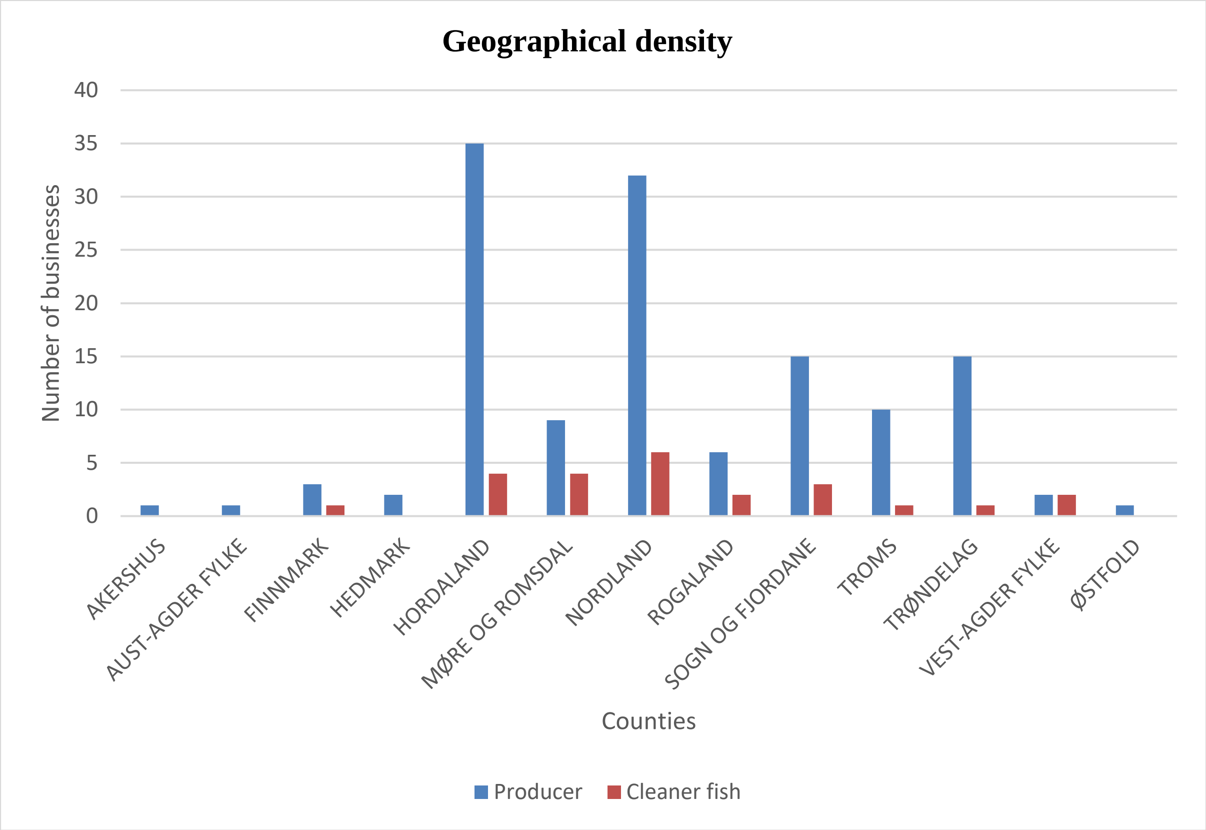

Figure 7-17 Geographical density of cleaner fish producers

Concluding remarks

The cleaner fish industry is facing a lot of challenges in the future. Laser technology, transparent lice, gene technology, and stronger regulations to mention a few. On the other hand, there is a dire need for cleaner fish, which can be observed from the development and continuous investment in new facilities. Up until now, the growth in demand has outweighed the growth in companies, and this trend seems to continue.

7.5 Alternative ways of dealing with fish health

The following segments of aquaculture have not arisen as a direct response to fish health-related issues. They will be able to operate regardless of what happens to the health-related challenges. Each segment has a different niche where it can contribute to prevent or treat disease. Thus, they make up an important piece of the whole puzzle.

7.5.1 Feed

Feed companies play an essential role in constituting a product that can foster healthy and nutritious salmon. They have gained a role countering lice, delivering special pellets containing remedies preventing and treating against the parasite. In the 2018 version of the document "Welfare-indicators for farmed salmon", many indicators regarding health and welfare are being directly linked to the feed and the feeding process. The feed is increasingly used to prevent the occurrence of salmon lice and various diseases (Overton & al., 2018). Feed plays an increasingly important part of providing good fish health, and further developments within this sector make it a favorable substitute for cleaner fish and other fish health services. Feeding is something one has to do whether or not the fish are infected, so if the farmers can treat them while feeding, this would be a preferred economic and welfare option. Removing or/and reducing treatment and the presence of cleaner fish will undoubtedly reduce stress and cost-inducing processes as discussed under the fish health report.

Looking at the financial development over time, two moments attract attention. MOWI entering the feed market in 2013 to decrease the feed prices, and Mitsubishi's acquisition of Cermaq in 2014 and the following restructuring of EWOS. The acquisition led to a change in accounting procedures, so the fiscal year for 2015 is somewhat misleading. Other operational costs for this segment were reduced with NOK 300 million from 2015 to 2016, which is almost entirely due to a change in that post caused by Ewos. In 2016, Biomar and Ewos had a substantial increase in cash holdings, and there was a general reduction in interest-bearing liabilities across the segment. These factors contributed to an abnormal spike in ROIC and a minor increase in EBITDA. MOWI entering has probably led to tougher competition on the feed market. Before they entered, the market had oligopolistic characteristics where EWOS, Skretting, and Biomar defined the operations. Integrating feed was probably a strategic beneficial move for MOWI, with advantageous effects for the farmers.

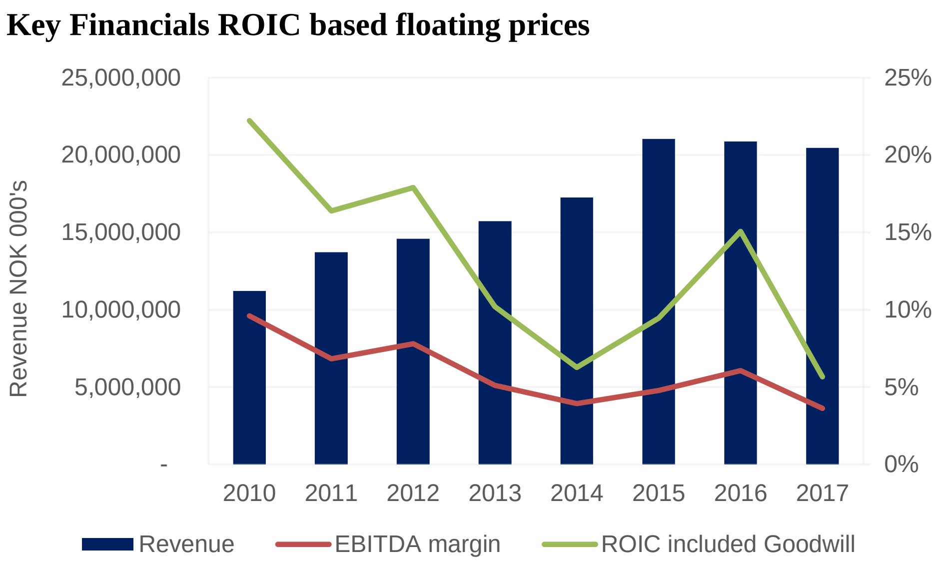

Figure 7-18 Key financials ROIC feed

The biggest challenge for feed producers going forward relates to the input factors of feed and, and how this affects fish health and welfare and nutritional value of the product. The institute of marine research is working on several alternatives (Jakobsen, 2019) to decrease the high amount of plant products. Going far down in the value chain and utilize easily accessible energy will be important. Research on insect meal shows promising results for fish health and taste (Nagelsen, 2018), but it has to be an economically viable option before the feed producers are going to apply it.

7.5.2 Eggs

Broodstock released in the area from Taskneset to Langøya has to be vaccinated. The food safety authority can impose vaccination in other areas if deemed necessary (Regulations on measures to prevent, limit, and combat PD in aquaculture animals, 2017). Localities with broodstock production are landbased and have established an infection barrier on production water. Alternatively, broodstock is produced on localities within separate broodstock zones (The Ministry of Industries and Fisheries, 2014-2015). The 40 broodstock permits distributed to commercial agents have a minimum demand of producing 1.3 billion roe a year (Directorate of Fisheries, 2017). For any given year, this translates to producing an amount equivalent to twice the demand of roe. The directorate of fisheries is still receiving a high number of applicants for broodstock permits even though the market has reached its capacity. From 2015 to 2017 the directorate of fisheries supervised eleven out of twelve holders of broodstock permits. The supervision was completed as system revisions on a company level, and specific localities were not controlled. Deviation from procedures was discovered on all facilities for the production of broodstock (Directorate of Fisheries, 2018).

Salmobreed will implement CT scanning in the selection process for picking the best breeding candidates. Carrying out this method, they expect to increase data accuracy (Aadland, 2019). Challenges regarding infectious disease transmitted directly through broodstock or environmental contamination are still prevalent, and there has not been a lot of studies conducted on the transmission of pathogens via milt. Solving this problem through genomic endeavors could provide a huge competitive advantage (Basic, 2019). In a study conducted by AquaGen in 2017 genomic selection against lice, they manage to reduce infestations with 40-55% (Aquagen, 2017). Each generation going through the selection process yields a reduction in infestations by 20-25%, and the future potential inspires optimism (Aquagen, 2017). QTL roe has yielded an improved resistance against IPN and contributed to removing a loss factor (AquaGen, 2013). QTL is an abbreviation for quantitative trait locus, and a QTL analysis is conducted if one wants to alter genes (Miles, n.d.).

Broodstock has gone through a substantial consolidation since the 2000s, and the number of permits and companies is reduced by over 40 p.p. (Norges Offentlige Utredninger, 2014). From 2010 total non-current assets have increased from NOK 100 million to NOK 1.4 billion. The application process for obtaining a broodfish permit was initiated in January 2008, and it changed the requirements of what the application should contain (The Directorate of Fisheries, 2017). Reduced number of permits, higher invested capital, and a demanding application make the barriers of entry high for Egg producers and the threat of new entrants low. In 2017, there were 124 smolt producers and 12 broodstock producers. The buyer to firm concentration ratio is high and contributes to a strong position for the broodstock producers. There are no available substitutes for the buyers, and they deliver steady EBIT margins around 10% for the entire period, indicating that they have some leeway. These facts indicate a low bargaining power of customers. I do not have insight into existing channels of distribution and actual switching costs, which could alter my perspective.

In the EBIT margin break down, the general trend for personnel expenses and other operating expenses has been retraction. The industry moves towards automated facilities with equipment for roe selection (Soltveit, 2018). The cost of materials is a relatively bigger expense in 2017 than for 2010, and the development is quite different from the rest of the industry. With more advanced equipment comes a higher demand for specialized workers, which could give them higher bargaining power.

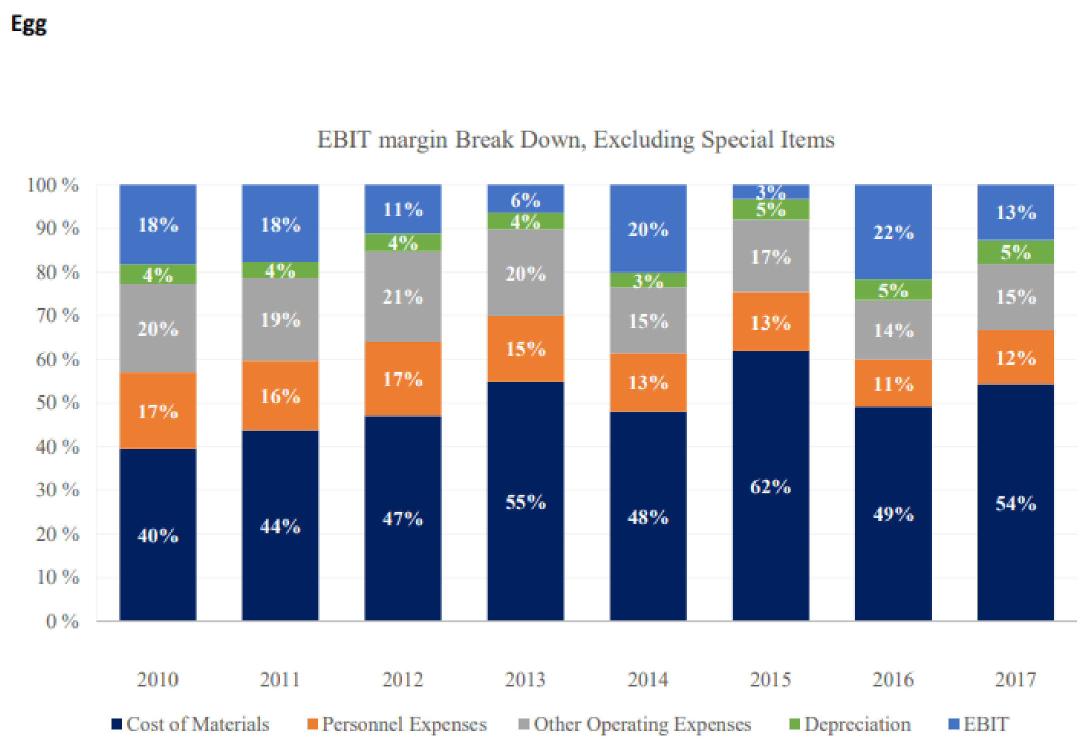

Figure 7-19 EBIT margin break down eggs

The number of companies has gone down for the period. The EBIT seems to follow the development in the salmon price with only dipping below 10% in 2013 and 2015. High entry barriers through an onerous application process and high capital requirements, low customer bargaining power/stable channels of distribution, and a general reduction in the number of operators make the period of observation characterized by low competitive rivalry.

Observing the development in revenue, EBITDA and ROIC, 2016 seem to have been a special year in terms of income and profits. A wider product range and a shift in demand towards improved products have ultimately led to increased prices. Broodfish is a very small part of egg producers revenue and an increased number of slaughtered broodfish have most likely nothing to do with the increased revenue[12]. In 2017, the cost followed the previous year's revenue increase, and EBITDA went back to the 2012-2015 level.

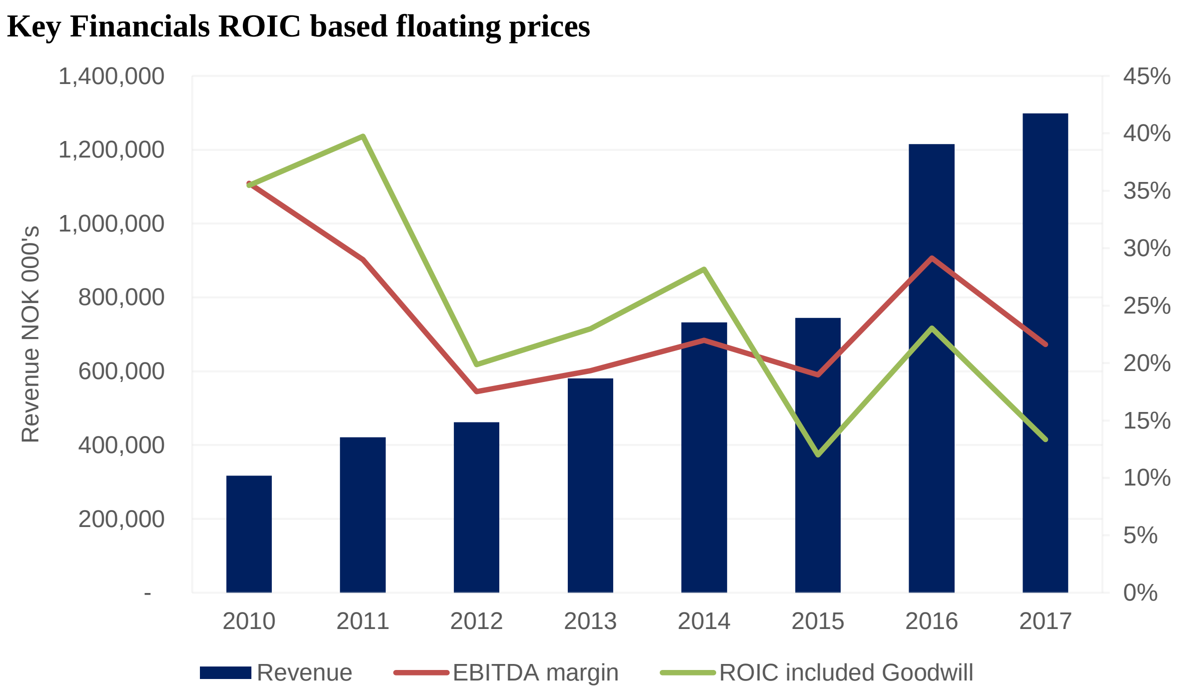

Figure 7-20 Key financials ROIC eggs

[12] Insight gain from a conversation with COO in Aquagen

7.5.3 Smolt

Every budget proposition made by the Norwegian government since the budget year of 2013, has indicated bad smolt quality as an important contributor to the high death rates during production at sea (The Norwegian Government, 2018). The Minister of Fisheries announced in 2016 that new legislation would lower the barriers to start with landbased aquaculture. This arrangement made it possible to receive permits without paying recompense and has lowered the threshold to start smolt production (The Norwegian Government, 2016).

Even though Bjørndal and Tusvik found that there is not a sizable economic difference in production cost for 100-g, 500-g, and 1000-g smolt, the industry pursues 500-g and 1000-g smolt in the belief that this will prove to be advantageous (Bjørndal & Tusvik, 2018). Ytrestøyl has looked into differences in growth at sea between 600-g and 100-g smolt. She claims that the traditional 100-g smolt is still the most efficient strategy (Ytrestøyl T. , 2018). Ytrestøyl clarifies that they did not take escape risk and lice pressure into the equation and that the conclusion is rather that there are many unanswered questions regarding the production of big post-smolt.

Public pushback might be imminent because The Norwegian Food Safety Authority has received several reports from facilities losing complete batches of smolt in a short period (Drønen, 2018). Many instances leading to mass death have uncertain causes, and preventative measures are not easy to commence.

In a report by SINTEF, they concluded that technical solutions regarding water quality, feed, transportation of sludge, and gene selection will have to improve to make sure land-based facilities can operate in a safe and sustainable matter (SINTEF Ocean AS, 2018). Reducing time at sea could provide positive environmental effects such as a reduced quantity of salmon lice, fewer escapees, recycled nutrition from sludge water, and lower biological risk in general (Kraugerud, 2019). Be that as it may, reduced time at sea has led to some challenges in smolt production, where young male salmon start the maturation process too early (Hoddevik, 2018).

Newcomers to smolt production are anyone who can obtain a permit to start breeding and have the necessary capital required to invest in facilities and equipment. The government has lowered the barrier to start smolt production, but the development has gone towards fewer companies and permits operated.

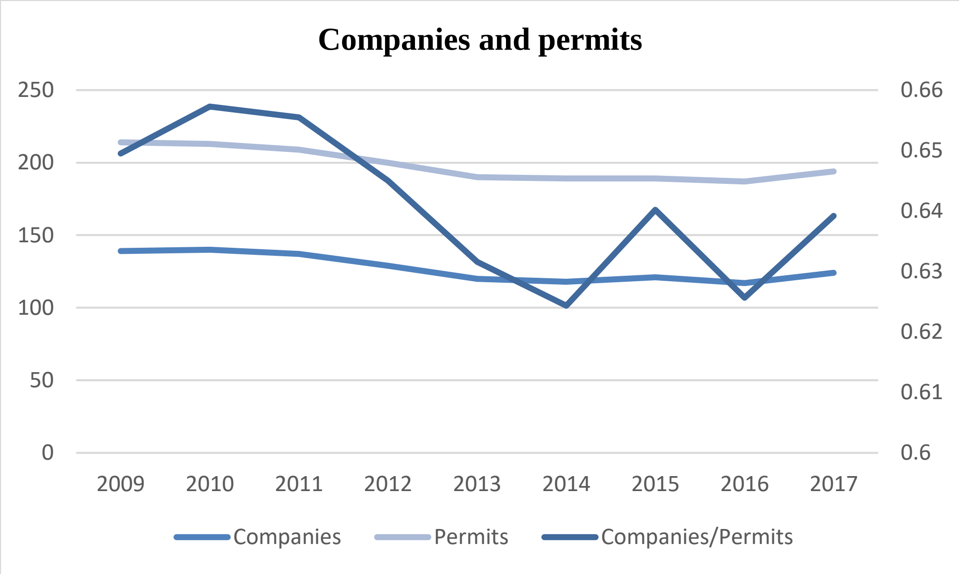

Figure 7-21 Companies and permits for smolt

Data source: (Directorate of Fisheries, 2019)

Looking at The Directorate of Fisheries statistics, one gets a sense of the recent development in capital investment. The market is aiming at economies of scale solutions, producing at a low unit cost. The profitability in this group is not strikingly high either, which an indicator of an industry where it has been easy to establish a business. However, if a large scale is necessary to compete going forward, it can become harder for small agents to establish a smolt company.

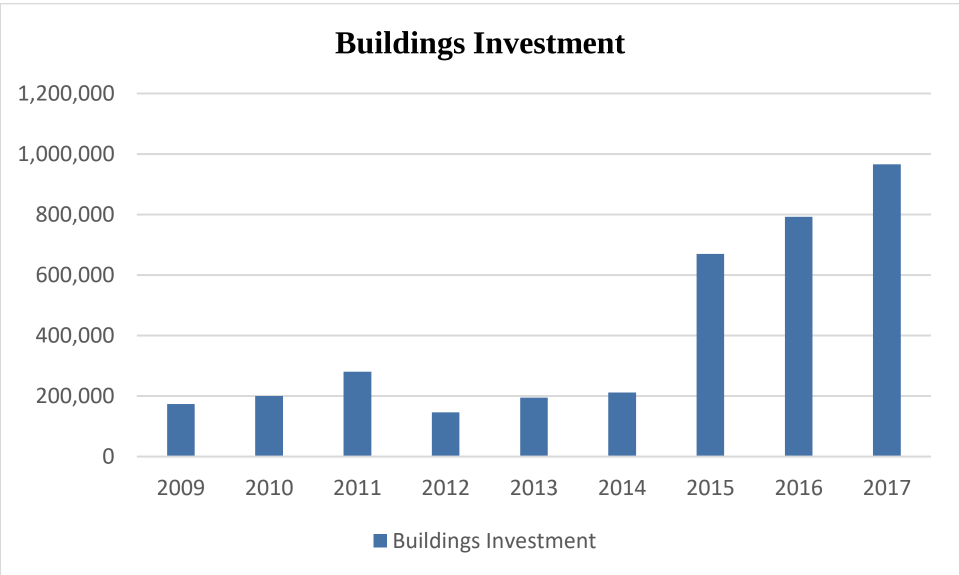

Figure 7-22 Buildings investment, smolt. Value in NOK 1000

Data source: (Directorate of Fisheries, 2019)

The graph below illustrates the development of total smolt value and value per smolt. Smolt value projection is going towards higher value per smolt, but a big weakness of this chart is that it does not take into account the advancement in post-smolt production.

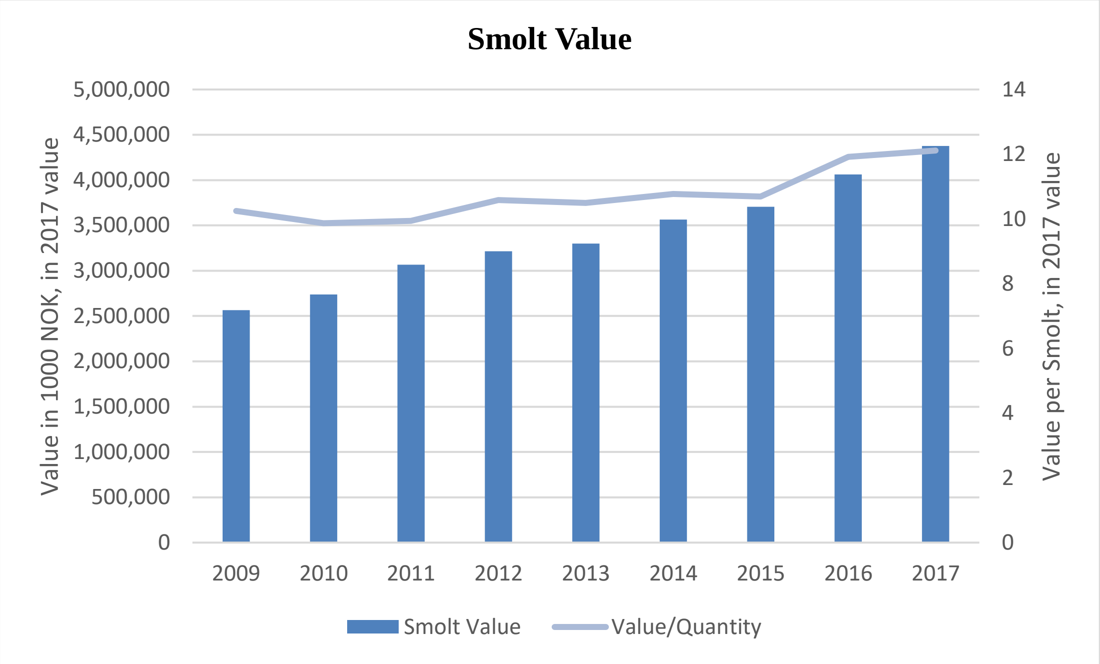

Figure 7-23 Smolt value

Data source: (Directorate of Fisheries, 2019)

Appraising the nature of the market, smolt and producers exists in a connected symbiosis where one cannot live without the other. It is hard to give an exact evaluation of switching costs for producers that are not vertically integrated. There is also a trend where producers administrate their smolt production and are vertically integrated. Egg producers are the most important supplier, and it is at the core of smolt operations. Several companies have already integrated egg production into their operations. Regarding suppliers of technological solutions, equipment, labor, and transport required to construct and operate the facilities, I assume a high supply and few transaction costs. RAS technology and other necessary equipment are delivered by a multitude of suppliers where transaction cost seems to be negligible. This will not be given any further consideration.

During the last five years, the number of smolt producers has oscillated around 120 companies. The value per smolt, adjusted to 2017 value, has accumulated steadily since 2009 and reached its highest point in 2017.

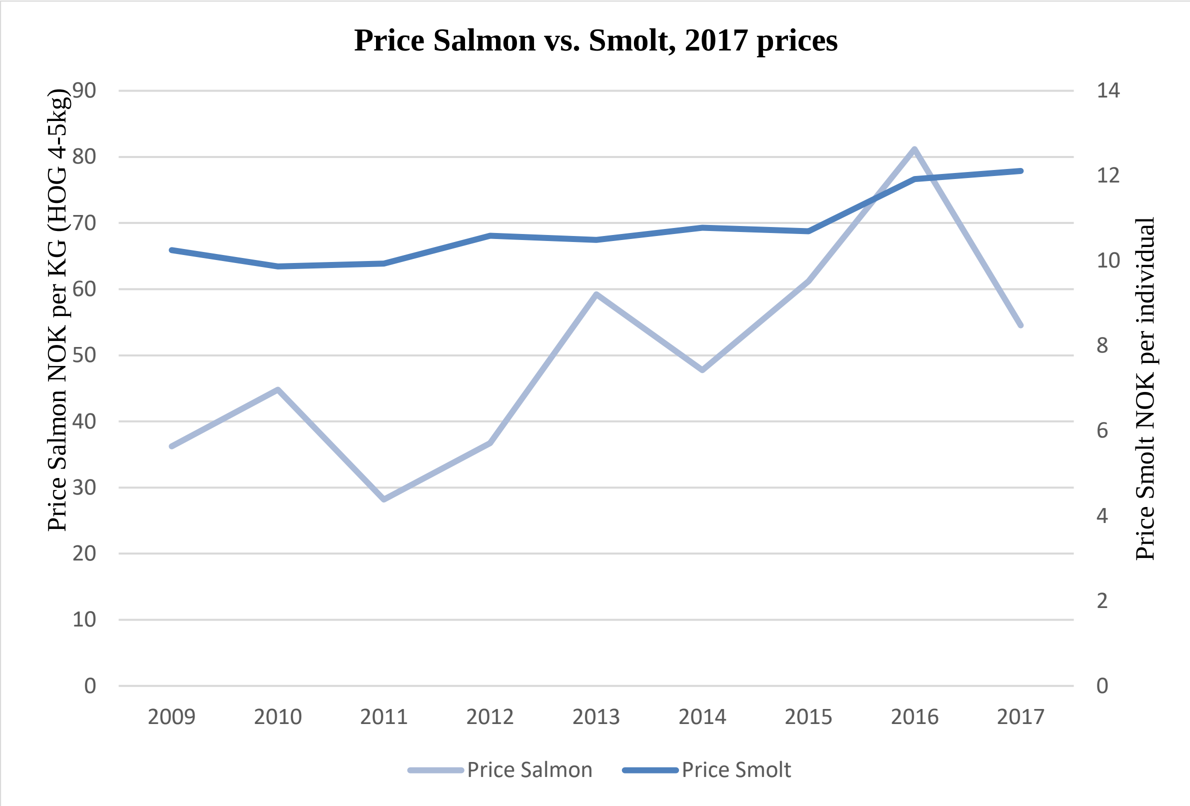

Figure 7-24 Price salmon vs. smolt

Data source: (Directorate of Fisheries, 2019)

The trend is headed towards RAS technology and bigger facilities (Dahle, et al., 2020) that could further contribute to fewer, bigger players and lower the competitiveness of the industry.

Concluding remarks

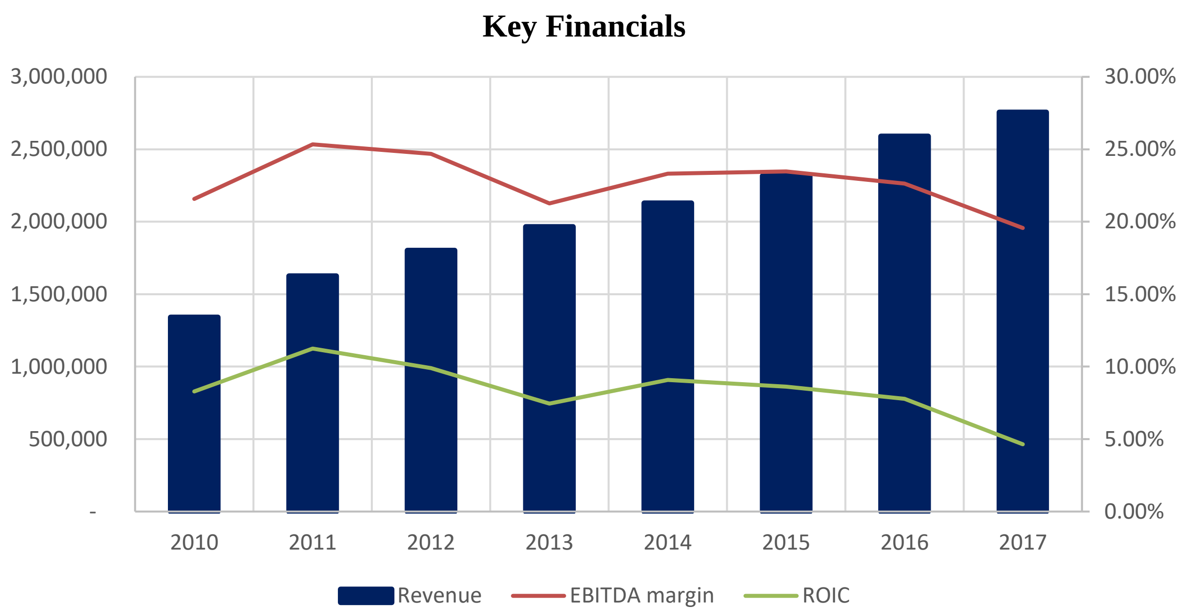

Figure 7-25 Key financials ROIC Smolt

Revenue growth has been stable throughout the entire period, however, EBITDA and ROIC have declined steadily since 2014. The accounting records “Land, buildings and other real estates” and “Machines and plants” have almost doubled in the time from 2014 to 2017. This has, in turn, led to a bigger growth in invested capital than in EBIT, hence the subsiding ROIC.

8. PMI Survey

The PMI survey I created is supposed to reflect the market anticipation of the industry in the foreseeable future. I sent it to over 700 aquaculture related businesses from 04.01.2019 to 04.15.2019, and a total of 114 respondents from businesses related to cleaner fish, eggs, equipment for aquaculture, feed carriers, feed producers, fish carriers, fish health, packaging, processing, service vessels, and smolt answered my inquiry. The companies were selected with the same method applied for generating financial statements[13]. The questionnaire was designed with simplicity in mind, so the threshold for participation was low. Recipients were asked to take a stand on four different statements, and rate them with an increase, no changes or decrease, and would, in turn, give the ratings a score of 1, 0.5, or 0 respectively. Adding the value of all responses for one statement and dividing it by the total number of respondents, gives the PMI score for one statement. The further away from 0.5, the score is, the greater the expected change would be.

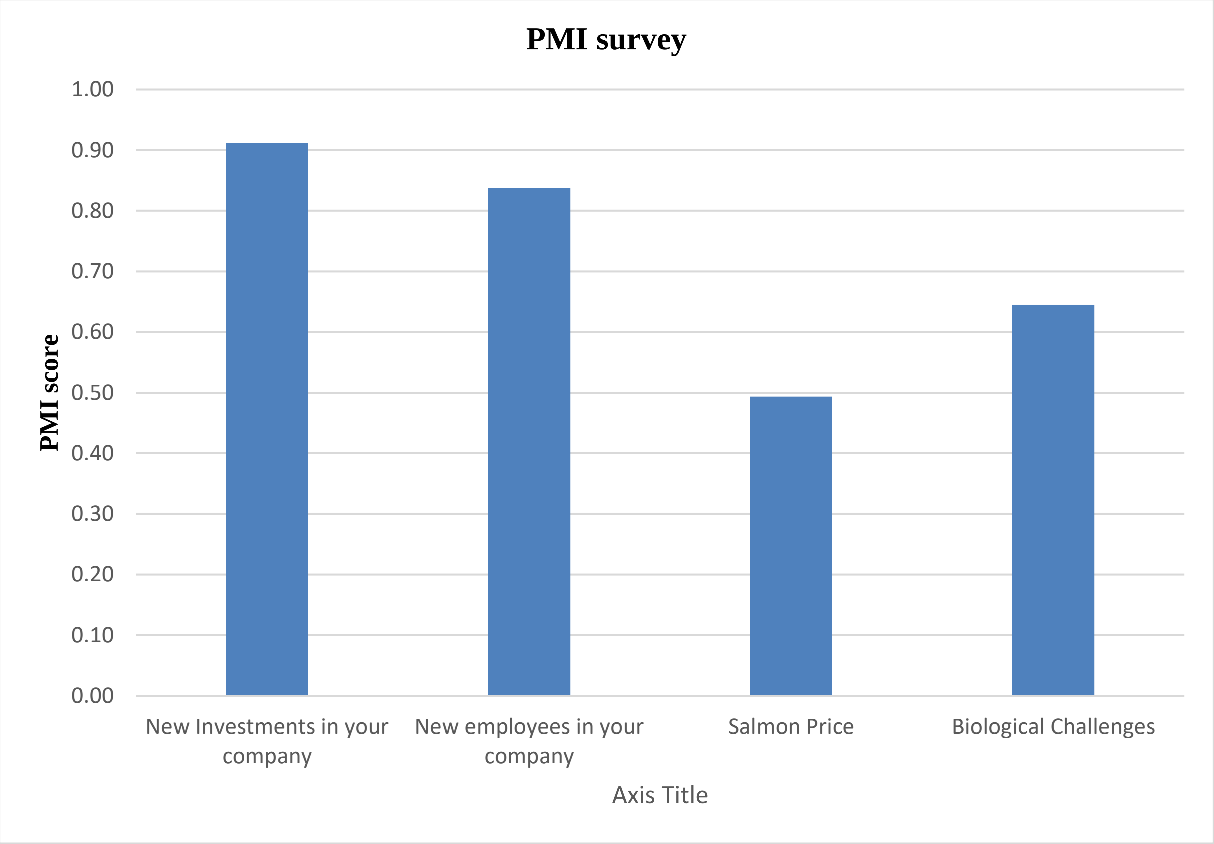

Figure 8-26 PMI survey

[13] See 5.3.1 Financial statements

The results show a promising near-term future for the industry. According to this survey, it is a clear trend towards increasing new investments and hire more people across the whole industry. Predictions about biological challenges are uncertain, and the responses vary considerably across different groupings. The trend is slightly towards increased biological challenges. Expectations regarding salmon prices are 0.49, and the variance between groups is small. Respondents expect no changes.

The PMI survey has a couple of weaknesses I would like to point out. A normal PMI is produced monthly and provides insight into continuous changes over time. For this reason, my survey could only be deemed as information useful to predict in a very short period. It could also be biased towards respondents working in companies doing better than average. The tendency for increasing new investments and hiring could be slightly overstated. If a business is doing well, one might unconsciously want to signal to other people how well you are doing (Hanson, 2017). The expectations for biological challenges could be understated. This bias could simply be due to a neglect of probability which is a tendency to underestimate or overestimate probabilities of different events occurring (Kahneman, 2011). New investments and new employees have a strong inclination for an increase, and one could add 25 respondents answering a decrease on top of the 114, before getting below a PMI score of 0.75.

9. Problem-solving matrix

In order to deal with the problems in aquaculture going forward, I am proposing a two-dimensional framework of how to deal with problems. This could be a useful tool when working towards solutions that are sustainable in the long run.

The x-axis of the matrix represents time, where the beginning of any problem-solving process represents a phase where you can prevent potential problems from having any negative consequences. However, as time passes, you cross over into the treatment phase. The transition is when the activity of solving a problem is preventative, but you are still treating an emerging/prevailing problem. As time goes on, one shift towards the right of the x-axis, the necessity for treating increases, and the possible solutions and problems increase. For aquaculture, eggs are preventative, smolt is in the transition between preventing and treating and the fish health segment is in the treatment stage.

Externalizing/ Preventing	Externalizing/ Treating
Internalizing/ Preventing	Internalizing/ Treating

Figure 9-27 Problem-solving matrix

Along the y-axis, you have the degree of externalization. The further away you are from origo, the more you look to the environment for your solutions. To make my point clear, I want you to imagine two entities, x, and y, living in an environment with z external factors. In this example, each entity can be arranged in α different ways in order to adapt to its environment. The total number of configurations for x or y will always be lower than x+z or y+z given that x and y's corresponding α is the same, so given no prior information, you would always start with trying different configurations for the entity you want to fix, before altering the other entity or the environment. The obvious weakness of my argument is the dependence of α different configurations in surrounding entities and the size of z. For aquaculture, one could say that the different configurations of putting forth a salmon (x) are a much bigger number than the different ways of dealing with the salmon lice (y). If the internalization argument were to hold, one would need the external factor z to be so big that y+z would be bigger than x.

The problem-solving matrix is meant as a guiding tool helping the problem solver towards a long-term satisfiable solution. It can be utilized by mapping different solutions so one could easily see the different possibilities in front of oneself, and rank them according to the dimensions.

10. Concluding remarks

The purpose of this investigation has been to examine, identify, and shed light on factors that will affect the aquaculture industry from a fish health perspective. Dealing with health issues will be crucial to sustaining profits in the years to come. The earlier in the process, the better. The aquaculture industry has put the salmon in an unnatural environment, and that creates some challenges it must resolve. How the industry should deal with the problems depends on how one categorizes the problems. I would start by internalizing or externalizing the problems by posing the question; "*do we need a stronger salmon or do we need to change its environment?".* The fish health segment in the aquaculture industry has arisen by tackling the challenges from an internalized perspective i.e. one thinks there is something wrong with the fish, and manipulating it will help. Smolt, egg, and feed businesses are also dealing with the challenges from an internalized perspective. This makes sense, given the nature of their operations. However, fish health and feed are mostly ways of treating problems that have arisen given the internal and external conditions. Dealing with fish health-related issues during the smolt and egg stage, on the other hand, takes a preventative approach. Selecting eggs for more robust fish would be one way to tackle the root causes of the problems, where the potential end goal would be to amalgamate a DNA combination creating a "super fish" that repels every challenge you hurl against it. Whether or not it is realistic to hope for a salmon that is immune to all health-related issues, a break-through that would make the salmon resistant against lice, to such a degree that it would satisfy the current regulations, could have a major impact in terms of minimizing stress-inducing treatment methods that are taxing on the salmon and the bottom line. I would argue that cleaner fish is an externalization of problems. In this case, you are not treating the salmon directly, but rather improving its environment by removing a problem after it has arisen.

In this thesis, we have seen that the biological problems are on the rise. However, we have also seen that the profits are great and businesses do not seem to be struggling on a macro scale. Incentives between businesses might not be aligned to facilitate it, but an interdisciplinary bioeconomic project investigating biological challenges with their respective economic impacts could be feasible and beneficial given the present-day financial and biological situation. This has not been discussed in any detail, but as we can see from the graph below, the producers, like several suppliers, have delivered high returns the recent years.

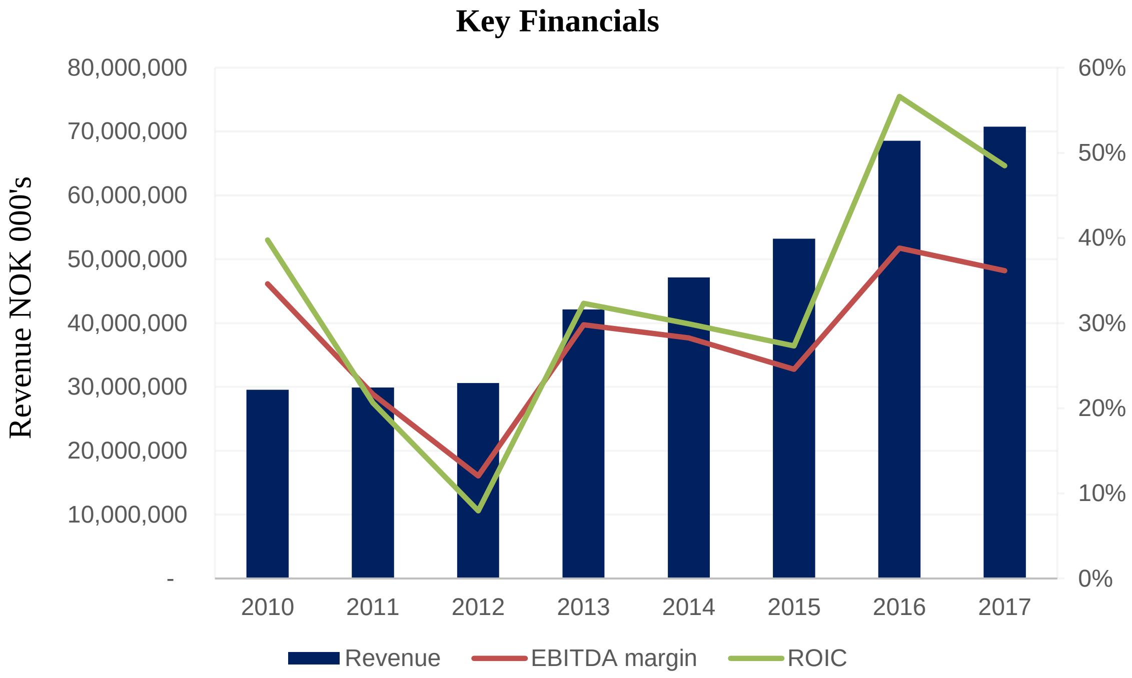

Figure 10-28 Key financials aquaculture producers

Surveillance and regulations imposed by the government will keep on demanding the industry to put up with tougher standards, nonetheless, they are not necessarily doing enough about the root cause of the challenges the industry is facing nor about how to resolve them in the long run. Looking at my research question, "*Will fish health-related issues have an economic impact on the aquaculture industry now and going forward?",* the answer is most likely yes. A whole industry has emerged to cater to fish health-related problems, besides, I have not presented the complete picture of the economic impact. As an example, service vessels are performing many activities on the pens, activities that come as a result of having to deal with salmon lice. Nevertheless, a high salmon price has yielded high profits, and if it stays that way, it will probably continue to yield high profits. Nonetheless, the costs are ramping up due to the biological challenges, and the industry has to continue its struggle for a healthy salmon.

11. References

Aadland, C. (2019, 11 02). *For the first time, this technology is going to select broodstock*. Retrieved from https://fiskeribladet.no/tekfisk/nyheter/?artikkel=65198

AquaGen. (2013, Juli 01). *QTL-rogn gir nedgang i IPN på nasjonalt nivå [QTL roe is causing a decline in IPN at the national level]*. Retrieved from AquaGen: https://aquagen.no/2013/07/20/qtl-rogn-gir-nedgang-i-ipn-pa-nasjonalt-niva/

Aquagen. (2017, December). *Avl for luseresistens virker [Breeding for lice resistance works]*. Retrieved from Aquagen, Rogninfo: https://aquagen.no/2017/12/08/avl-luseresistens-virker/

Armstrong, V. (2015, Oktober 16). *Pharmaq tapte rettskrangel om laksevaksine [Pharmaq lost legal dispute over salmon vaccine]*. Retrieved from E24: https://e24.no/privat/forbrukerrettigheter/pharmaq-tapte-rettskrangel-om-laksevaksine/23543633

Aubell, C., & Hamarsland, I. H. (2018). The Economic Effects of the. Retrieved from https://openaccess.nhh.no/nhh-xmlui/bitstream/handle/11250/2559623/masterthesis.PDF?sequence=1&isAllowed=y

Auchterlonie, N. E. (2014). *Scottish Aquaculture's Utilisation of Environmental Resources.* Retrieved from http://www.sarf.org.uk/cms-assets/documents/152955-102338.sarf082.pdf

Basic, D. (2017). *Rensefisk og risiko for overføring av smitte til oppdrettslaks [Cleaning fish and risk of transmission of infection to farmed salmon]*. Retrieved from https://vkm.no/risikovurderinger/allevurderinger/rensefiskogrisikoforoverforingavsmittetiloppdrettslaks.4.d44969415d027c43cf6562a.html

Basic, D. (2019, Mars 27). *Norwegian Scientific Committee for Food and Environment*. Retrieved from VKM: https://vkm.no/risikovurderinger/allevurderinger/handelmedfrossenmelkefraoppdrettsfiskrisikoforsmitteoverforing.4.fc28d8f161931feec52c1bc.html

Berge, A. (2016). *Åpnet rensefiskanlegg til 110 millioner kroner [Opened cleaning fish facility to NOK 110 million]*. Retrieved from https://ilaks.no/apnet-rensefiskanlegg-til-110-millioner-kroner/

Berk, J., & DeMarzo, P. (2016). *Corporate Finance* (4th ed.). USA: Pearson Higher Ed USA.

Berle, H., & Rim, S. Y. (2018). The Cost of Sea Lice and Its. Retrieved from https://openaccess.nhh.no/nhh-xmlui/bitstream/handle/11250/2560665/masterthesis.PDF?sequence=1&isAllowed=y

Bjørkli, J. (2002). *Protein og energiregnskap hos laks, kylling, gris og lam [Protein and energy account in salmon, chicken, pig and lamb].* Ås: Norwegian University of Life Sciences (UMB).

Bjørndal, T., & Tusvik, A. (2018). *Economic analysis of alternative production methods within aquaculture.* Retrieved from https://openaccess.nhh.no/nhh-xmlui/handle/11250/2573420

Bjørshol, B., Hellberg, H., & Dalum, A. S. (2019, April 09). *Økende interesse for veterinær spesialistutdanningen i akvakultur [Increasing interest in veterinary specialist training in aquaculture]*. Retrieved from IntraFish: https://www.intrafish.no/kommentarer/1750723/okende-interesse-for-veterinaer-spesialistutdanningen-i-akvakultur

Bruinsma, J. (2009). *The resource outlook to 2050.* Retrieved from http://www.fao.org/3/a-ak971e.pdf

Brun, E., Aamelfot, M., Qviller, L., Lyngstad, T., Kristoffersen, A. B., Sindre, H., & Falk, K. (2018). *Betydning av ILAV HPR0 for utbrudd av ILA [Significance of ILAV HPR0 for ILA outbreak].* Oslo: Veterinærinstituttet.

Bundli, V. A., & Liltvedt, K. K. (2012). Fish Farm Ecology. Retrieved from https://openaccess.nhh.no/nhh-xmlui/bitstream/handle/11250/169549/bundli%20og%20liltvedt%202012.PDF?sequence=1&isAllowed=y

Costa-Pierce, B. A. (2016). *Ocean foods ecosystems for planetary survival.* The University of New England.

Dahle, S. W., Bakke, I., Birkeland, M., Nordøy, K., Dalum, A. S., & Attramadal, K. J. (2020). *Production of lumpfish in RAS with distinct water treatments.* SINTEF.

Damodaran, A. (2020). *ROIC by sector (US)*. Retrieved from http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/mgnroc.html

Directorate of Fisheries. (2016). *Biomasse [Biomass]*. Retrieved from https://www.fiskeridir.no/Akvakultur/Drift-og-tilsyn/Biomasse

Directorate of Fisheries. (2016). *Oppdaterte retningslinjer for behandlingen av søknader om utviklingstillatelser [Updated guidelines for processing development permit applications]*. Retrieved from https://www.fiskeridir.no/Akvakultur/Nyheter/2016/0616/Oppdaterte-retningslinjer-for-behandlingen-av-soeknader-om-utviklingstillatelser

Directorate of Fisheries. (2017). Annual report. Retrieved from https://www.fiskeridir.no/Om-oss/AArsrapport

Directorate of Fisheries. (2017). Profitability Analysis. *Lønnsomhetsundersøkelse for produksjon av laks og regnbueørret [Profitability survey for salmon and rainbow trout production]*.

Directorate of Fisheries. (2018). Supervision of broodstock permits. Retrieved from https://www.fiskeridir.no/Akvakultur/Drift-og-tilsyn/Tilsynskampanjer/Tilsyn-med-stamfisktillatelser

Directorate of Fisheries. (2019). Retrieved from Salmon and trout: https://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Laks-regnbueoerret-og-oerret

Directorate of Fisheries. (2019). *Matfiskproduksjon av laks, regnbueørret og ørret [Food fish production of salmon, rainbow trout and trout]*. Retrieved from https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Akvakulturstatistikk-tidsserier/Laks-regnbueoerret-og-oerret/Matfiskproduksjon

Drønen, O. A. (2018). *Significant risk in the operation of RAS facility*. Retrieved from https://www.kyst.no/article/betydelig-risiko-i-drift-av-ras-anlegg/

EFSA. (2018, 11 20). *Dioxins and related PCBs: tolerable intake level updated.* Retrieved from EFSA: http://www.efsa.europa.eu/en/press/news/181120

Fenstad, A. (2018). *Lakselusa har blitt blank. Det mener laser-John er godt nytt for teknologien hans [Salmon lice have become shiny. This means laser-John is good news for his technology]*. Retrieved from https://www.tu.no/artikler/lakselusa-har-blitt-blank-og-gar-under-radaren-til-rensefisken-det-mener-laser-john-er-godt-nytt-for-teknologien-hans/449106

FOR-2003-08-12-1052. (2003, January 01). Forskrift om krav til teknisk standard for anlegg som nyttes i oppdrettsvirksomhet [Regulations on requirements for technical standards for facilities used in fish farming]. Oslo: The Directorate of Fisheries.

FOR-2018-09-05-1320. (2019, January 01). Forskrift om avgift til forskning og utvikling i fiskeri- og havbruksnæringen [Regulation on fees for research and development in the fisheries and aquaculture industry]. Oslo: The Directorate of Fisheries. Retrieved from https://lovdata.no/dokument/SF/forskrift/2018-09-05-1320?q=for-2018-09-05-1320

Fraslin, C., Brard-Fudulea, S., D'Ambrosio, J., Bestin, A., Charles, M., Haffray, P., . . . Phocas, F. (2019, Mars 18). Rainbow trout resistance to bacterial cold water disease: two new quantitative trait loci identified after a natural disease outbreak on a French farm. France.

Garseth, Å. H., Svendsen, J., Fritsvold, C., Mikalsen, A. B., , & . (2017). *Kardiomyopatisyndrom (CMS) hos laks.* Oslo: Veterinærinstituttet.

Grindheim, J. (2019, April 09). *Slik testa forskarane korleis laksen reagerte på varmt vatn [How the researchers tested how the salmon reacted to hot water]*. Retrieved from Fiskeribladet: https://fiskeribladet.no/tekfisk/nyheter/?artikkel=66262

Hanson, R. (2017). *The Elephant in the Brain.* Oxford University Press.

Hjeltnes, B., Bang, J. B., Bornø, G., Haukaas, A., Walde, C. S., & . (2018). *Fiskehelserapporten [The Fish Health Report].* Veterinærinstituttet.

Hoddevik, B. (2018, Oktober 15). *Kjønnsmodning kan gi problemer i moderne smoltproduksjon [Sexual maturation can cause problems in modern smolt production]*. Retrieved from IMR: https://www.hi.no/hi/nyheter/2018/oktober/kjonnsmodning-smoltproduksjon

Høgåsen, H. R. (1999). *Physiological Changes Associated with the Diadromous Migration of Salmonids.* NRC Monograph.

Hommedal, S. (2019, April 01). *Avslører fiskens helse ved hjelp av røntgen og beinknusing [Reveals fish health using X-ray and bone crushing]*. Retrieved from IMR: https://www.imr.no/hi/nyheter/2019/april/avslorer-fiskehelse-med-rontgen

Hooke, R. L. (2012). *Land transformation by humans: A review.* GSA TODAY. Retrieved from https://www.geosociety.org//gsatoday/archive/22/12/pdf/i1052-5173-22-12-4.pdf

Jakobsen, A. (2018). *Lusespiseren sliter i sterk strøm og høy temperatur [The lice eater is struggling in high current and high temperature]*. Retrieved from https://www.hi.no/hi/nyheter/2018/oktober/lusespiseren-sliter-i-sterk-strom-og-hoy-temperatur

Jakobsen, A. (2019, Mars 05). *Hva skal fremtidens oppdrettsfisk spise? [What will the future farmed fish eat?]*. Retrieved from Institute of Marine Research: http://www.imr.no/hi/nyheter/2019/mars/nasf-hva-skal-fremtidens-oppdrettsfisk-spise

Jansen, M. D., Jensen, B. B., Taksdal, T., Sindre, H., Lillehaug, A., & . (2015). *Pankreassykdom hos laksefisk - en review med fokus på forebygging, kontroll og bekjempelse [Pancreatic disease in salmonids - a review focusing on prevention, control and control].* Oslo: Veterinærinstituttet.

Kahneman, D. (2011). *Thinking, Fast and Slow.* Farrar, Straus and Giroux.

Karlsen, Ø. F. (2016). Kunnskapsstatus som grunnlag for kapasitetsjustering innen produksjonsområder basert på lakselus som indikator [Knowledge status as basis for capacity adjustment in production areas based on salmon lice as indicator]. Retrieved from https://www.imr.no/filarkiv/2016/04/kunnskapsstatus_lakselus_som_indikator.pdf/nb-no

Kearns, M. (2016, March 16). *Over 24 million Chilean salmon now dead from toxic algae bloom*. Retrieved from Seafoodsource: https://www.seafoodsource.com/news/supply-trade/over-24-million-chilean-salmon-now-dead-from-toxic-algae-bloom

Kraugerud, R. L. (2019). *Å stenge laksen inne kan gi bedre oppdrett [Caging the salmon can provide better farming]*. Retrieved from https://forskning.no/fisk-nofima-oppdrett/a-stenge-laksen-inne-kan-gi-bedre-oppdrett/1290928

Kristiansen, T. (2019, Mars 27). *Tema: Fiskevelferd [Theme: Fish welfare]*. Retrieved from IMR: https://www.hi.no/hi/temasider/akvakultur/fiskevelferd

Kvamme, B. (2017). *Trafikklysmodellen og kunnskapsgrunnlaget [The traffic light model and the knowledge fundation]*. Retrieved from http://img4.custompublish.com/getfile.php/3763427.2344.abpdxdwpqx/Havforskningsinstituttet.pdf?return=www.sfj.no

Marine Harvest ASA. (2017). *Høringssvar: Forslag til tilpasning av regelverket for rensefisk [Consultation response: Proposal for adaptation of the regulations for cleaning fish]*. Retrieved from https://www.regjeringen.no/contentassets/dade9bb267a740438a7e64d812fed87d/marine-harvest.pdf?uid=Marine_Harvest.pdf

Mekonnen, M. H. (2010). *The Green, Blue, and Grey water footprint of farm animals and animal products.* Retrieved from https://ris.utwente.nl/ws/portalfiles/portal/5146067/Report-48-WaterFootprint-AnimalProducts-Vol1.pdf

Mikkelsen, E. K. (2018). *Skiftende Vindretning [Sea Change]*.

Miles, C. M. (n.d.). *Quantitative Trait Locus (QTL) Analysis*. Retrieved from https://www.nature.com/scitable/topicpage/quantitative-trait-locus-qtl-analysis-53904/

Nagelsen, V. (2018, November 28). *Insekter er bra mat for laksen [Insects are good food for salmon]*. Retrieved from Institute of Marine Research: https://www.hi.no/hi/nyheter/2018/november/insekter-er-bra-mat-for-laksen

NNR. (2012). *Nordic Nutrition Recommendations 2012: Integrating Nutrition and Physical Activity, edition 5.* Copenhagen: Secretary of the Nordic Council of Ministers Nordic Council of Ministers.

NOAA, F. (2019, 04 08). Retrieved from NOAA Fisheries: https://www.fisheries.noaa.gov/species/atlantic-salmon

Norges Offentlige Utredninger. (2014). *Sjøtmatindustrien [Seafood Industry].*

Norwegian Veterinary Institute. (2020, March 9). *Louse off 2 – Kostnadseffektiv lakselusvaksine; utvikling og effektvurdering [Louse off 2 - Cost-effective salmon lice vaccine; development and impact assessment]*. Retrieved from https://www.vetinst.no/forskning-innovasjon/pagaende-forskningsprosjekter/louse-off-2-kostnadseffektiv-lakselusvaksine-utvikling-og-effektvurdering

Nøstbakken, O. J. (2014). *Contaminant levels in Norwegian farmed Atlantic salmon (Salmo salar) in the 13-year period from 1999 to 2011*. Environment International.

NYTEK-regulation. (2011). *Forskrift om krav til teknisk standard for flytende akvakulturanlegg (FOR-2011-08-16-849) [Regulation on requirements for technical standards for floating aquaculture facilities]*. Retrieved from https://lovdata.no/dokument/SF/forskrift/2011-08-16-849

Olsen, S. (2017, December 04). *Pharmaq åpnet ny virusfabrikk [Pharmaq opened new virus factory]*. Retrieved from https://ilaks.no/pharmaq-apnet-ny-virusfabrikk-det-er-en-viktig-milepael-for-oppdrettsnaeringen/

Olsen, S. (2019, April 24). *Mindre behov for beroligende laksemiddel dempet resultatet til Scan Aqua [Less need for sedative solvents dampened Scan Aqua's results]*. Retrieved from https://ilaks.no/mindre-behov-for-beroligende-laksemiddel-dempet-resultatet-til-scan-aqua/

Overton, K., & al., e. (2018). *Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review.* John Wiley & Sons Australia, Ltd.

Pettersen, J. M., Rich, K. M., Jensen, B. B., & Aunsmo, A. (2015). *The economic benefits of disease triggered early harvest: A case study of pancreas disease in farmed Atlantic salmon from Norway.*

Poppe, T. (2018). *Oppdrettsnæringens martyrer [The Martyrs of the Aquaculture Industry]*. Retrieved from https://www.harvestmagazine.no/artikkel/sjomatnasjonen-del-8-oppdrettsnaeringens-martyrer?fbclid=IwAR152U7abnHEKEVznyhEufku077lNyNlFFv_YpOCOZERyughV7JsS7VxXd0

Regulation on granting permits. (2013). *Forskrift om tildeling av løyve til havbruk med matfisk av laks, aure og regnbogeaure i sjøvatn i 2013 (FOR-2013-06-24-754) [Regulations on granting permits for aquaculture with salmon, aure and rainbow aure in seawater in 2013]*. Retrieved from https://lovdata.no/dokument/SF/forskrift/2013-06-24-754

Regulations on measures to prevent, limit, and combat PD in aquaculture animals. (2017). Forskrift om tiltak for å forebygge, begrense og bekjempe pankreassykdom (PD) hos akvakulturdyr [Regulations on measures to prevent, limit, and combat PD in aquaculture animals]. *FOR-2017-08-29-1318*. Retrieved from https://lovdata.no/pro/#document/SF/forskrift/2017-08-29-1318?searchResultContext=1131&rowNumber=1&totalHits=10

Rueness, E., Berg, P. R., Gulla, S., Halvorsen, K., Järnegren, J., Mamstrøm Martin, . . . Rimstad, E. (2019). *Assessment of the risk to Norwegian biodiversity from import of wrasses and other cleaner fish for use in aquaculture.* Oslo.

Salmonexpert. (2019, April 04). *GSI da a conocer mejor dieta funcional contra SRS [GSI discloses the best functional diet against SRS]*. Retrieved from Salud: https://www.salmonexpert.cl/article/gsi-da-a-conocer-mejor-dieta-funcional-contra-srs/

Saue, O. A. (2018, September 04). *Marknaden for PD-vaksine snudd på hovudet [The market for PD vaccine turned on its head]*. Retrieved from ilaks: https://ilaks.no/marknaden-for-pd-vaksine-snudd-pa-hovudet-no-har-pharmaq-60-prosent-marknadsdel/

Saue, O. A. (2018, Juni 01). *Slik kan datainnsamling bidra til betre fiskehelse [Data collection can contribute to improved fish health]*. Retrieved from ilaks: https://ilaks.no/vil-revolusjonere-oppdrettsbransjen-med-datainnsamling/

SINTEF Ocean AS. (2018). *Consequence analysis of land-based farming of salmon - fish, and post-smolt.* Retrieved from https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2564532

Soltveit, T. (2018, Oktober 22). *Kan få forbud mot å skrive ut antibiotika-resepter [Prohibition against prescribing antibiotic prescriptions might come]*. Retrieved from Kan få forbud mot å skrive ut antibiotika-resepter [Prohibition against prescribing antibiotic prescriptions might come]: https://www.kyst.no/article/kan-faa-forbud-mot-aa-skrive-ut-antibiotika-resepter-1/

Soltveit, T. (2018, August 31). *Kan produsere 100 millioner rognkorn i nytt anlegg [Can produce 100 million roe grains in new plant]*. Retrieved from https://www.kyst.no/article/kan-produsere-100-millioner-rognkorn-i-nytt-anlegg/

Soltveit, T. (2018, April 10). *Nytt rognkjeksskjul skal gjøre produksjonen lettere [A new lump roe shed will make production easier]*. Retrieved from https://www.kyst.no/article/nytt-rognkjeksskjul-skal-gjoere-produksjonen-lettere/

Soltveit, T. (2018). *Potensielt dramatisk, nytt lakselus-funn [Potentially dramatic, new salmon lice discovery]*. Retrieved from https://www.kyst.no/article/potensielt-dramatisk-nytt-lakselus-funn/

Stensvold, T. (2017). *De har skutt 500 mill laserpulser mot millioner av lus – ikke en eneste laks er meldt skadet [They have shot 500 million laser pulses against millions of lice - not a single salmon is reportedly damaged]*. Retrieved from https://www.tu.no/artikler/de-har-skutt-500-mill-laserpulser-mot-millioner-av-lus-ikke-en-eneste-laks-er-meldt-skadet/409231

Sunde, L. M. (2019). *Biologisk bekjempelse [Biological control]*. Retrieved from https://www.sintef.no/ocean/satsinger/lakselus/#Biologiskbekjempelse

The Aquaculture Act. (2005). *Lov om akvakultur (LOV-2005-06-17-79) [Law regarding aquaculture]*. Retrieved from https://lovdata.no/dokument/NL/lov/2005-06-17-79

The Directorate of Fisheries. (2017, Mars 30). *Retningslinjer for søknad om stamfiskoppdrett [Guidelines for application for broodstock farming]*. Retrieved from Akvakultur: https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Saertillatelser/Stamfisk

The Directorate of Fisheries Institute of Marine Research. (1974). Lover og Forskrifter av betydning for oppdrettsnæringen [Laws and Regulations of importance to the aquaculture industry]. Retrieved from https://brage.bibsys.no/xmlui/bitstream/handle/11250/114234/fhb_1974_05.pdf?sequence=1

The Government. (2014). *Nye tiltak mot lakselus [New measures against salmon lice]*. Retrieved from https://www.regjeringen.no/no/aktuelt/Nye-tiltak-mot-lakselus/id2351302/

The Ministry of Industries and Fisheries. (2014-2015). Predictable and environmentally sustainable growth in Norwegian salmon and trout farming. Retrieved from https://www.regjeringen.no/no/dokumenter/meld.-st.-16-2014-2015/id2401865/sec10?q=stamfisk#match_2

The Ministry of Trade, Industry, and Fisheries. (2014, December 09). *Fiskehelse/lakselus [Fish health/Salmon lice]*. Retrieved from Regjeringen: https://www.regjeringen.no/no/tema/mat-fiske-og-landbruk/fiskeri-og-havbruk/rad-1/oppdrettslaksen/sykdom/id607091/

The Ministry of Trade, Industry, and Fisheries. (2019, Januar 17). *Strengere regler for bruk av lusemidler [Stricter rules for the use of lice remedies]*. Retrieved from Regjeringen: https://www.regjeringen.no/no/aktuelt/strengere-regler-for-bruk-av-lusemidler/id2625923/

The Norwegian Directorate of Health. (2018, 11 20). *Kostråd om fisk og sjømat [Dietary advice on fish and seafood]*. Retrieved from Helsenorge: https://helsenorge.no/kosthold-og-ernaring/kostrad/spis-fisk-oftere

The Norwegian Food Safety Authority. (2017). *Mattilsynets arbeid med dyrevelferd [The Norwegian Food Safety Authority's work with animal welfares]*. Retrieved from https://www.regjeringen.no/contentassets/f3630965333e4af2a5f1007dbdc0bad9/arsrapport-mattilsynet-2017-arb-med-dyrevelferd.pdf

The Norwegian Food Safety Authority. (2019). *Rensefiskkampanje vil gi viktig ny kunnskap [Cleaning fish campaign will grant new important knowledge]*. Retrieved from https://www.mattilsynet.no/fisk_og_akvakultur/akvakultur/rensefisk/rensefiskkampanje_vil_gi_viktig_ny_kunnskap.30882

The Norwegian Government. (2016). *New rules for land-based farming*. Retrieved from https://www.regjeringen.no/no/aktuelt/nye-regler-for-landbasert-oppdrett/id2502424/

The Norwegian Government. (2017, June 27). *Endringer i reglene for rensefisk [Change in the rules for cleaning fish]*. Retrieved from https://www.regjeringen.no/no/aktuelt/endringer-i-reglene-for-rensefisk/id2563342/

The Norwegian Government. (2017). *Forskrift om tiltak for å forebygge, begrense og bekjempe pankreassykdom (PD) hos akvakulturdyr [Regulations on measures to prevent, limit, and control pancreatic disease (PD) in aquaculture animals]*. Retrieved from https://www.regjeringen.no/no/dokumenter/pd-forskriften/id2568631/

The Norwegian Government. (2018). *Prop. 1 S.* Retrieved from https://www.regjeringen.no/no/dokumenter/prop.-1-s-20182019/id2613210/sec1

The Norwegian Government. (2019, May 3). *Vil ta bedre vare på rensefisken [Will take better care of the cleaning fish]*. Retrieved from https://www.regjeringen.no/no/aktuelt/vil-ta-bedre-vare-pa-rensefisken/id2600180/

The Norwegian Institute of Public Health. (2019, Mars 07). *2018: Oppdrettsnæringen bruker stadig mindre legemidler mot lakselus [2018: The aquaculture industry is using ever less drugs against salmon lice]*. Retrieved from FHI:

https://www.fhi.no/nyheter/2019/2018-oppdrettsnaringen-bruker-stadig-mindre-legemidler-mot-lakselus/

The Norwegian Scientific Committee for Food and Environment. (2019, October 11). *Assessment of the risk to Norwegian biodiversity from import of wrasses and other cleaner fish for use in aquaculture.* Retrieved from https://vkm.no/download/18.22fe061816d90c026b4a890d/1570782153468/Assessment%20of%20the%20risk%20to%20Norwegian%20biodiversity%20from%20import%20of%20wrasses%20and%20other%20cleaner%20fish%20for%20use%20in%20aquaculture.pdf

The Norwegian Veterinary Institute. (2020). *Fiskehelserapporten [The Fish Health Report].* Retrieved from https://www.vetinst.no/rapporter-og-publikasjoner/rapporter/2020/fiskehelserapporten-2019

Thomsen, C. K. (2018, 11 21). *Fakta om dioksiner og dl-PCB [Facts about dioxins and dl-PCBs].* Retrieved from FHI: https://www.fhi.no/ml/miljo/miljogifter/fakta/dioksiner-og-dl-pcb-faktaark/#helseskader-av-dioksiner-og-dlpcb-i-mat

Thonhaugen, M. (2016, Februar 15). *Om ikke lenge vil oppdrettsindustrien møte veggen [In no time, the aquaculture industry will meet the wall]*. Retrieved from NRK: https://www.nrk.no/nordland/_-om-ikke-lenge-vil-oppdrettsindustrien-mote-veggen-1.12795508

Tvete, A. (2016). An approach to salmon farming in Norway. Retrieved from https://openaccess.nhh.no/nhh-xmlui/bitstream/handle/11250/2432689/masterthesis.PDF?sequence=1&isAllowed=y

UN. (2017, 07 21). *World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100*. Retrieved from United Nations: https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html

Viken, T. (2018, June 21). *Lakseauksjonen er fullført [The salmon auction is complete].* Retrieved from https://www.regjeringen.no/no/aktuelt/lakseauksjonen-erfullfort/id2605186/?fbclid=IwAR23tROBNqNrtVFr9k4TaWd5Tyh7zz2PMkSZEAzzHlg3pyw1AIwJ92VLlq0

Vøllestad, A. (2018, 07 29). *Laks [Salmon]*. Retrieved from SNL: https://snl.no/laks

Winther, U. Z. (2009). *Carbon footprint and energy use of Norwegian seafood products.* SINTEF. Retrieved from https://www.sintef.no/globalassets/upload/fiskeri_og_havbruk/fiskeriteknologi/filer-fra-erik-skontorp-hognes/carbon-footprint-and-energy-use-of-norwegian-seafood-products---final-report---04_12_09.pdf

Ytrestøyl, T. (2018, March). *Large smolt not always best*. Retrieved from https://nofima.no/en/nyhet/2018/03/large-smolt-not-always-best/

Ytrestøyl, T. A. (2014). *Resource utilization of Norwegian salmon farming in 2012 and 2013.* Nofima.

12. Appendix

The attachments contain a list of the companies I have used to make the aggregated financial statements.

12.1 List of fish health companies

ORG NUMBER	COMPANY NAME
886953402	PHARMAQ
964873755	EUROPHARMA AS
963201230	VESO APOTEK - VETERINÆRMEDISINSK OPPDRAGSSENTER AS
978603769	MSD ANIMAL HEALTH NORGE
937375158	AKVAPLAN-NIVA AS
983297951	AQUA PHARMA AS
985525331	PATOGEN AS
916763816	ÅKERBLÅ AS
880356372	SCANVACC AS
986208933	KYSTLAB AS
982749042	PHARMAQ ANALYTIQ
982226163	AQUA KOMPETANSE AS
897958872	FISHGUARD AS
986284311	LABORA AS
995153637	VAXXINOVA NORWAY AS
993351695	LABOLYTIC AS
983829775	MARIN HELSE AS
883023722	AQUALIFE SERVICES LTD
983212344	AQUATIC CONCEPT GROUP
987868600	HAVLANDET FORSKNINGSLABORATORIUM
975353346	PHARMAQ SETTVAC AS
994936557	HYGIENEGRUPPEN AS
976820630	AGRONOR AS
912156346	AQUATIC CONSULT AS
912044408	FISH VET GROUP
996198944	SEAFOOD SECURITY AS
986381961	MAT MILJØLABORATORIET AS

996830845	PROVACC AS
917816387	NORSK OPPDRETTSVAKSINERING AS
977515033	BÅTSFJORD LABORATORIUM AS
998058376	RESIPIENTANALYSE AS
998200202	MICROSAFE AS
976814355	BIONOR LABORATORIES AS
917209391	AQUALIFE SERVICES AS
976597087	ALKONTROLL AS
991783245	HYDRA VEGA AS
917529574	TUVESUND AS
983515827	AQUATIQ CHEMISTRY AS

12.2 List of cleaner fish companies

ORG NUMBER	COMPANY NAME
996463052	NORSK OPPDRETTSSERVICE AS
983350755	RYFYLKE RENSEFISK AS
897741962	NAMDAL RENSEFISK AS
815276302	TJELDBERGODDEN RENSEFISK AS
990212422	SENJA AKVAKULTURSENTER AS
985574979	MØRKVEDBUKTA AS
915278043	AUSTEVOLL RENSEFISK AS
995725134	STEINVIK RENSEFISK AS
992259418	ONARHEIM BRUK AS
914880378	VEST AQUA BASE AS
995088053	NORDLAND RENSEFISK AS
814911632	LUMARINE AS
891198752	ECOMARIN SEAFARM AS
916044402	LØNNINGDAL RENSEFISK AS
996929922	ARCTIC CLEANERFISH AS
982732727	HAVLANDET MARIN YNGEL AS

981955943	INDUSTRISKJELL AS
915884482	FINNMARK RENSEFISK AS
991895000	TOMMA RENSEFISK AS
915238750	RENSEFISKGRUPPEN AS
913673271	SØSAND LEPPEFISK AS
917385793	HELGELAND HAVBRUKSTJENESTER AS
918931961	REFLEX SHIPPING AS
915634222	TINGVOLLFISK AS
918710450	HELGELAND LUMPSUCKER AS

12.3 List of feed companies

ORG NUMBER	COMPANY NAME
988044113	SKRETTING AS
937843860	BIOMAR AS
979184832	EWOS AS
911610744	MOWI FEED AS
994046055	ALLER AQUA A/S
911501252	EWOS INNOVATION AS
915070388	AQUAMED AS
915887872	BOTNGAARD BIOPROTIX AS
976527623	STATKORN AQUA AS

12.4 List of egg companies

ORG NUMBER	COMPANY NAME
964367701	AQUA GEN AS
983506925	SALMOBREED AS
995262894	NORDNORSK STAMFISK AS
992130636	SALTEN STAMFISK AS
988718181	SVANØY HAVBRUK AS
975798186	RAUMA STAMFISK AS
944609938	TROMS STAMFISKSTASJON AS
918695818	SALMAR GENETICS AS
981043286	AKVAFORSK GENETICS
898844412	OSLAND STAMFISK AS
916288182	SKJERNESET FISK AS
916000030	SALMOBREED SALTEN AS

12.5 List of smolt companies

ORG NUMBER	COMPANY NAME
813837692	TYTLANDSVIK AQUA AS
821018692	AS SETTEFISKANLEGGET LUNDAMO
841139402	RAUMA SÆTRE AS
864943632	FLATANGER SETTEFISK AS
884625882	LØDINGEN FISK AS
887850852	FOSSING STORSMOLT AS
890011632	MÅSØVAL SETTEFISK AS
911942429	FIRDA SETTEFISK ARNAFJORD AS
912257460	STEINVIK SETTEFISK AS
914976391	SALANGFISK AS
915272932	SUNNFJORD STORSMOLT AS
916157509	FJORDSMOLT AS
917396752	NRS SETTEFISK AS
917533539	SALBU PRODUKSJON AS

918335323	LERØY SJØTROLL KJÆRELVA AS
918482784	OSAN SETTEFISK AS
918904913	SØRFOLD SMOLT AS
918916466	SØRSMOLT AS
919592303	SVABERGET SMOLT AS
921044747	AS SÆVAREID FISKEANLEGG
921136846	ASK DAMBRUK AS
921716605	SMØLA KLEKKERI OG SETTEFISKANLEGG AS
924931671	STRØMSNES AKVAKULTUR AS
928925129	SOL SMOLT AS
935701643	SALMAR SETTEFISK AS
936100112	URKE FISKEOPPDRETT AS
936768148	AS FEMANGERLAKS
937543948	HYEN FISK AS
938413789	ELVENESSTRAND SMOLT AS
939377697	FRØFISK AS
939530185	FIRDA SETTEFISK AS
939612424	LIALAKS AS
939817646	HJELVIK SETTEFISK A/S
940316073	BARLINDBOTN SETTEFISK AS
942273266	AUSTEFJORDEN SMOLT AS
946432121	STRAUMSNES SETTEFISK AS
948825627	HAUKVIK KRAFT-SMOLT AS
951790850	AKVAFARM AS
952982389	SANDE SETTEFISK AS
953000105	NEPTUN SETTEFISK AS
957175708	BRAKEDAL SETTEFISK AS
957896650	ASTAFJORD SMOLT AS
958438370	NYE ÅRØY KLEKKERI AS
958716796	ÅSEN SETTEFISK AS
958916116	FIRDA SETTEFISK ALVØEN AS
962339662	SILVER SEED AS
964943818	VIKAN SETTEFISK AS

966950153	ELVEVOLL SETTEFISK AS
971129735	RANFJORD FISKEPRODUKTER AS
974536463	BINDALSSMOLT AS
976969413	GRYTÅGA SETTEFISK AS
977106206	RAUMA EIK AS
977552087	BJØLVE BRUK AS
978647103	OLDEN OPPDRETTSANLEGG AS
979398875	FISTER SMOLT AS
979724551	BOLSTAD BRUK AS
979993528	SALTEN SMOLT AS
981979583	SAGAFJORD SEA FARM AS
982326435	SEAMATECH AS
982671809	FJON BRUK AS
982849284	NJORD SALMON AS
983599834	TRØNDERSMOLT AS
983664490	EIDESVIK SETTEFISK AS
983957536	GJØLANGER SETTEFISK AS
984436335	SALAR BRUK AS
985191840	VILLA SMOLT AS