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Economic Decision Making in Salmon Aquaculture

An Analysis of the Investment Behavior for Production Licenses under the Norwegian Traffic Light System

Dominik Josef Flatten

Supervisor: Lassi Ahlvik

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in memoriam Manfred Ernst Reichel

Quidquid agis, prudenter agas et respice finem.

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Abstract

The analysis of 'The Economic Impacts of the Product Area Regulation' by Pettersen Aubell & Haugen Hamarsland (2018) indicated a discrepancy between the calculatory willingness-to-pay for increased production capacity and the actually realized prices. This thesis will explain this paradox and provide an unprecedented view into the economic decision making of Norwegian salmon grow-out farmers in terms of long-term investment decisions (i.e. purchase of additional production capacity) in order to reduce the gap between what bioeconomic modeling suggests as ideal and actual decisions made.

The detailed analysis of the Norwegian salmon aquaculture industry shows that bioeconomic modeling in aquaculture generally misses out on taking into consideration that parameters such as market prices, production costs, production technology, and environmental conditions change over time. This is anticipated by salmon grow-out farmers and included into their investment decisions. The analysis identified four main future developments that support a today's investment into increased production capacity.

Firstly, breeding programs will advance out-of-season smolts and enable salmon grow-out-farmers to release the fish flexibly all year round. This will reduce production and price cycles and stabilize the market. Second, the sea lice problem is about to be solved by lumpfish deployment. As soon as an own aquaculture is established for this species, salmon mortality can be significantly decreased. Thirdly, the climate change will increase sea-water temperatures which will improve growth conditions along the Norwegian coast, particularly in northern Norwegian regions. Fourthly and lastly, market prices have increased substantially in the last three years. As the market features an unsatisfied demand, prices are not expected to decrease in the following years and lucrative production margins support positive investment decisions for volume increases.

Innovative production technologies, i.e. land-based and offshore aquaculture, represent the largest degree of uncertainty to future industry developments as their licensing is not well-elaborated, yet. Currently running under development licenses, land-based and offshore operations bear the greatest potential for growth and their future development, both technologically and license-wise, should be carefully observed.

Keywords: Norwegian salmon aquaculture, production licenses, Production Area Regulation, bioeconomic modeling

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Abbreviations & Glossary

CAGR – **C**ompound **A**nnual **G**rowth **R**ate

CCS – **C**losed **C**ontainment **S**ystem

EBIT – **E**arnings **B**efore **I**nterest and **T**axes

EBITDA – **E**arnings **B**efore **I**nterest **T**axes, **D**epreciation and **A**mortization

FAO – **F**ood and **A**griculture **O**rganization of the United Nations

FCR – **F**eed **C**onversion **R**ate
Kilo feed per kilo fish produced

FIFO – **F**ish **I**n – **F**ish **O**ut Ratio

HOG – **H**ead-**O**n-**G**utted
see WFE

ISA – **I**nfectious **S**almon **A**naemia

MAB – **M**aximum **A**llowed **B**iomass

NQSALMON – **N**ASDA**Q** **Salmon** Index

ONP – **O**pen Net-**P**en

PD – **P**ancreas **D**isease

ROI – **R**eturn **o**n **I**nvestment

WFE – **W**hole **F**ish **E**quivalent
A standard weight denomination after gutting

WTP – **W**illingness**-t**o**-P**ay

1. Introduction

1.1 Rationale

Even though the Norwegian (and worldwide) salmon aquaculture industry is a comparably young industry with its roots in the early 1970s, it is also a knowledge-based industry "where nearly all economic and market research has been carried out" (Asche & Bjørndal, 2011, p. 151). Some argue that productivity could still be improved and production could be increased by an additional 35 % if the entire industry exploited given production capacities as productively as the industry's five top players (Nystøyl, et al., 2013). However, salmon aquaculture is definitely "in the forefront when it comes to technology, innovation and productivity development" (Asche & Bjørndal, 2011, p. 3).

As a consequence, the industry's research focus has shifted from classical aquaculture economics with purely economic scenarios and efficiency considerations to sustainability aspects and the handling of environmental challenges (Hersoug, 2015). Essential to the management of environmental issues are governmental regulations as players of any industry involving externalities rarely have any incentive to internalize the environmental impacts of their operations (Kolstad, 2011).

Whereas the motivation behind early regulations from 1973 onwards was rooted in the establishment of secure workplaces, regulations of the last twenty-five years rather aimed at the maintenance of an economically and environmentally sustainable industry (Nærings- og fiskeridepartementet, 2015). This also includes the industry's most recent regulation from October 2017, the Production Area Regulation (English for 'produksjonsområdeforskriften').

In short, the Production Area Regulation divides the Norwegian coast in a traffic light system into 13 production areas and steers production growth or reduction in these areas based on the mortality risk from lice infestation for populations of wild salmon (Nærings- og fiskeridepartementet, 2017a). Such a regulation strictly regulating production capacity has multifarious impacts for each fish farmer and the entire industry.

Analyzing 'The Economic Impacts of the Product Area Regulation', Pettersen Aubell & Haugen Hamarsland (2018) uncovered a paradox. According to their analyses, the investment in new production capacity (in the form of licenses) led to a positive net effect in only three out of the thirteen production areas under the new regulation. However, the first sale of additional production capacity in January 2018 after the introduction of the regulation was a tremendous success and over 97 % of the offered capacity could be sold (Nærings- og fiskeridepartementet, 2018a). This trend continued in June and September 2018 after Pettersen Aubell & Haugen Hamarsland (2018) finished their work, when salmon grow-out farmers bought 99.7 % of the auctioned capacity (Nærings- og fiskeridepartementet, 2018c).

Estimating the willingness-to-pay (WTP) for changes in capacity constraint, Pettersen Aubell & Haugen Hamarsland (2018) built their analysis upon Asche & Bjørndal's (2011) calculatory solution to the optimal rotation problem in salmon aquaculture who based their work on Faustmann's formula for managing forest rotation. Given the charactersitic similiarties between forestry and fish farming and the formula's academic omnipresence, Faustmann's work constitutes the basic framework for most bioeconomic modeling in aquaculture (Guttormsen, 2008). Hence, the found paradox seems to reveal a common misconception in bioeconomic modeling in aquaculture.

Given the deviations from bioeconomic analysis, this raises the question of how investment decisions are made in the Norwegian aquaculture industry and what factors shape or play into these decisions. In an attempt to illuminate why salmon farmers entered the 'battle for space' (Solås, 2017) and deviate from the theoretically optimal 'racing line' set by Pettersen Aubell & Haugen Hamarsland (2018), a thorough industry analysis is required. Combining this analysis with quantitative data and statistics from the Norwegian Directorate of Fisheries and other sources will reveal valuable insights and shed a new light on salmon grow-out farmers' investment behavior. Ultimately, the findings will be found useful for future theoretic and academic decision modeling in salmon aquaculture.

1.2 Aims & Objectives

The overall aim of this thesis is to provide an unprecedented view into the economic decision making of Norwegian salmon grow-out farmers in terms of long-term investment decisions (i.e. purchase of additional production capacity) in order to reduce the gap between what bioeconomic modeling suggests as ideal and actual decisions made. In order to be able to make tangible recommendations for future decision modeling in salmon aquaculture, this thesis is structured according to the following objectives:

1. To critically review and extensively examine industry literature on salmon market mechanisms and the production process with a special focus on the decision variables of salmon grow-out farmers *[Secondary Research]*
2. To critically review and extensively examine industry literature on the regulation of the Norwegian salmon aquaculture with a special focus on the role of production licenses, the 'Product Area Regulation' and the 2018 production license sale *[Secondary Research]*
3. To critically analyze the investment behavior for production licenses of Norwegian salmon grow-out farmers *[Primary Research]*
4. To develop recommendations for new aspects or emphases to be considered in future bioeconomic decision modeling in salmon aquaculture *[Recommendations]*

Based on the fulfilment of these objectives, this thesis will answer the following research question:

What is the salmon grow-out farmers' motivation and economic reasoning behind their investment behavior for production licenses under the Norwegian traffic light system?

1.3 Outline

In order to meet the aforementioned objectives, this introductory Chapter 1 will be followed by four additional chapters. Chapter 2 contains all secondary research activities with a literature review critically reviewing and extensively examining the Norwegian salmon aquaculture industry. Chapter 3 comprises the analysis part of this thesis discussing and reflecting upon salmon grow-out farmer's motivation and economic reasoning behind their investment behavior for production licenses. Chapter 4 draws conclusions and makes recommendations for aspects and emphases to be considered in future bioeconomic decision modeling in salmon aquaculture. Chapter 5 elaborates on the research constraints and points out opportunities for future academic research.

2. Literature Review

Meeting thesis objectives 1 and 2, this chapter aims to provide the groundwork and identifies the major research themes for the analysis part of this thesis. With this end in view, Section 2.1 and Section 2.2 will introduce the Norwegian aquaculture industry as well as biological and technological foundations. The latter are of fundamental importance due to the limitations they pose to the entire production process and their broad implications for the salmon market. These implications will be elaborated on in Section 2.3 – Market Mechanisms. Section 2.4 will then chronologically go through the production process and reflect upon the decision variables salmon grow-out farmers can influence throughout the salmon's life cycle – starting from smolt and ending with the harvest. In the next step, Section 2.5 will provide background knowledge with respect to the industry regulation and particularly introduce production licenses, the Production Area Regulation, and the 2018 production license sale. Next, the mechanics of bioeconomic models will be reviewed in Section 2.6 for a basic understanding of how they work towards maximizing the grow-out farmers' profit per production license. Particularly Asche & Bjørndal 's (2011) solution to the optimal rotation problem will be presented. With this broad background knowledge, the work by Pettersen Aubell & Haugen Hamarsland (2018) can be presented in Section 2.7 and the paradox uncovered in their analyses understood. Before the primary research part try to explain this paradox by investigating salmon grow-out farmers' investment behavior, Section 2.8 will summarize the literature review and segue into the analysis chapter by presenting the major research themes.

2.1 The Norwegian Salmon Aquaculture Industry

This section is meant to prevent any ambiguousness in terms of terminology, scope and focus of the thesis and to provide a general understanding of the historical background of salmon aquaculture. Emphasizing the worldwide importance of salmon aquaculture as an economic branch but also for the supply of the world population with nutritious food and animal protein, the economic development and size will also be presented.

2.1.1 Salmon Aquaculture Defined – Scope & Focus

According to the Food and Agriculture Organization of the United Nations (FAO) (1988),

> [a]quaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the

> rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.

Even though the FAO's definition includes all kinds of species, "salmon and shrimp are the leading species in modern industrialized aquaculture" (Asche & Bjørndal, 2011, p. 1). Out of the six salmon species that are commercially relevant, three are farmed and only *Salmo salar* is native to the Atlantic Ocean and hence farmed in Norway (Asche & Bjørndal, 2011). Therefore, this species, also called Atlantic salmon, will constitute the focus of this thesis for which all other species can be ignored both in biological as well as economical terms.

Even though in practice there is a "continuum of operation modes" (Asche & Bjørndal, 2011, p. 8), aquaculture systems can usually be classified into three different categories by their economically most relevant criterion – intensity:

1. Extensive production systems
2. Semi-intensive production systems
3. Intensive production systems

Intensity, in this case, refers to and depends on the degree of control, which Anderson (2002) also works out as the most differentiating factor between fisheries and aquaculture. Specifically, he refers to the control of the environment, production, and marketing systems and establishes a close relation to the strength of property rights (Anderson, 2002). This is important to note because the term 'intensity' is used for other connotations within salmon aquaculture, as well. For example, in his book 'Physiology of Fish in Intensive Culture Systems', Wedemeyer's (1996) 'intensity' refers to the requirement for flowing water. Edwards (1993), again, classifies the categories based on the extent of nutritional input (i.e. feed).

Setting terminology, a final clarification has to be made with respect to the term 'closed' that is frequently used when referring to production processes and systems in aquaculture. Asche & Bjørndal (2011) use the term 'closed' synonymously for 'intensive' and refer to the facts that the salmon is reared in confined areas (such as sea pens) and that the production is not dependent on the inputs from wild populations. Many other authors, however, use this term rather geographically for differentiating land-based rearing of aquatic species in raceways, tanks and ponds from 'open' aquaculture systems within natural seaways (Sauthier, et al., 1998). Since land-based farming of salmon is still in its infancy and keeps struggling with profitability due to high investment costs (EY, 2018), this promising but not yet economically viable type of aquaculture is merely treated as a side issue in 2.2.3 – Future Technology I: Closed Containment Systems. In consequence, further elaboration on the definition of ‘closed’ and ‘open’ production processes is not required. This thesis will use the term ‘closed’ in the context of the production technology only.

The fact that salmon aquaculture is operated in intensive culture systems, defined by their high degree of control, is, however, important to be kept in mind due to its multifarious implications for the economic decision making. Having comprehensively set scope and focus of the thesis and defined the industry meant to be investigated, a short overview of its history can is provided in the following.

2.1.2 A Historical Overview

The earliest form of aquaculture dates back to the Neolithic age around 4000 before Christ (BC) in Europe and “consisted of trapping wild aquatic animals in lagoons, ponds or small shallow lakes” (EC, 2019), so that they would always be available. Early historical roots of cage culture have been documented by You Hou Bin and can be traced back to ancient China to about 2000 BC (Azevedo, et al., 2018).

Throughout historical development where various advanced civilizations further developed different techniques of fish husbandry, the 19th century can be regarded as the ‘golden age of biology’. Amongst others, Charles Darwin, Louis Pasteur, and Gregor Mendel sowed the seeds for the development of what we consider modern salmonid aquaculture today (Tides Canada, 2015). Then, the biological discoveries of the previous century could be taken one step further and “specific health and dietary needs of fish at the different stages of its development” (EC, 2019) were discovered in the mid-20th century. The floating cage, developed in Japan in the 1960s, constituted the final innovation that enabled the farming of Atlantic salmon in Europe (EC, 2019).

With its extremely long and sheltered coastline of in total 101,000 km (Klinkenborg, 2013), equal to two and a half circumnavigations of the earth, and suitable sea-water temperature conditions (Braathen Thyholdt, 2014), Norway was predestined to quickly develop the economic size to be illustrated in the following subsection.

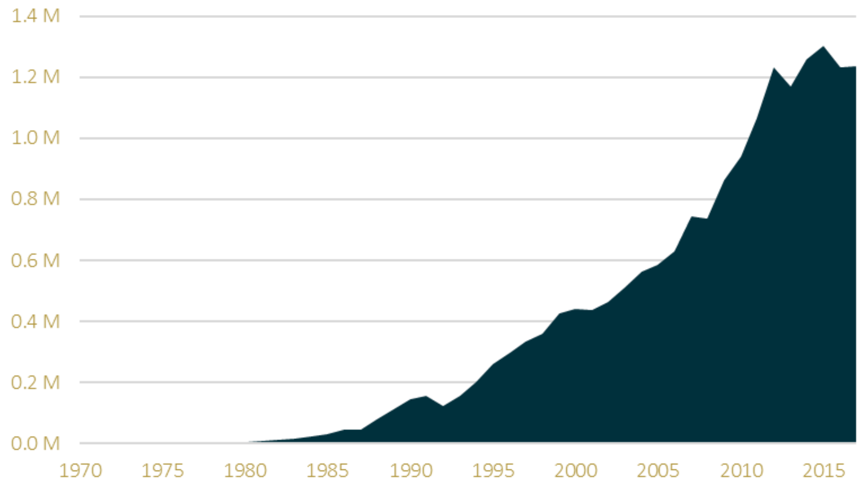
2.1.3 Economic Development & Size

After the historical development described in the previous subsection, salmon farming became a success story of the 1970s and 1980s. Up until then, salmon had been a highly luxurious product, but the farms cropping up in the fjords and bays of Norway made it available to a broad range of customers at reasonable prices (EC, 2019). “[S]ince that time aquaculture has developed into a major industry in coastal areas. In Norwegian aquaculture, intensive farming of Atlantic salmon is by far the most important activity, accounting for more than 80 percent of the total Norwegian aquaculture production” (FAO, 2019a).

Investigating most recent output figures, the production of salmon in 2017 was valued 61,6 billion NOK (Statistisk sentralbyrå, 2019a) and secured industry employment of more than 8,000 people (Statistisk sentralbyrå, 2019b). Starting at a production of Atlantic salmon of 50 tons in 1970, Norway has meanwhile grown to the largest producer in the world with a total production of almost 1.24 million tons in 2017. This yields a compound annual growth rate (CAGR) of 23.46 % over the entire period. With an output of 360,806 tons in 1998, the CAGR of the last twenty years amounts to 6.35 %. Even the CAGR of the last ten years is still as high as 5.30 % with a production of 737,694 tons in 2008 (FAO, 2019b; The Directorate of Fisheries, 2019). The production of Atlantic salmon in Norway over the last 48 years from 1970 until 2017 is displayed in Figure 1.

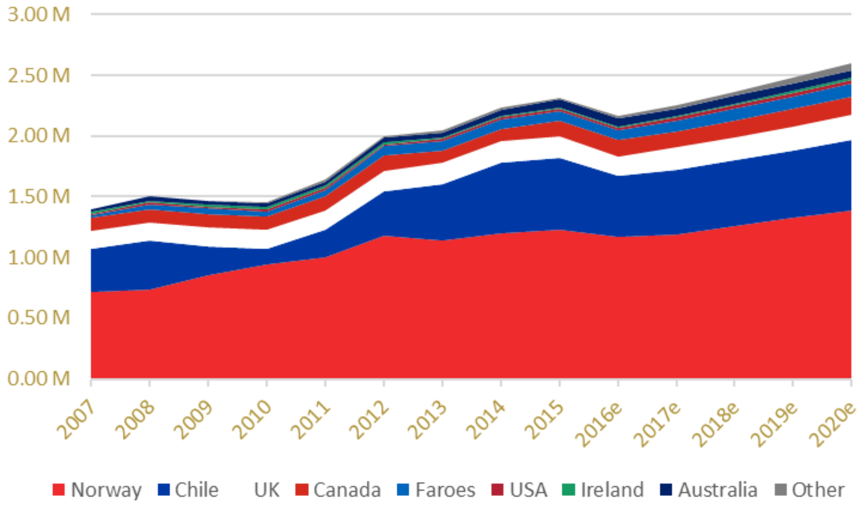
Taking on a global perspective, “Norway contributes more than 50 % of the global salmon production and […] is expected to maintain this market leading position in the years to come” (EY, 2018, p. 13). The distribution of the world production of Atlantic salmon between the producing countries is illustrated by Figure 2. Given the huge production volumes and Norway’s comparatively small population of about 5.3 million (Statistisk sentralbyrå, 2019c), around 95 % of Norway’s salmon production is exported (EY, 2018).

Figure 1 – Production of Atlantic Salmon in Norway in tons, 1970 – 2017



Based on FAO, 2019b

Figure 2 – World Production of Atlantic Salmon by Country in tons, 2007 – 2020



Adapted from EY, 2018

Shifting the perspective once again to an outlook into future developments, growth is expected to further diminish and settle at a CAGR-level of 4 % for the following years until 2021 (Marine Harvest, 2018).

> "The background for this trend is that the industry has reached a production level where biological boundaries are being pushed. It is therefore expected that future growth can no longer be driven by the industry and regulators as measures are implemented to reduce its biological footprint. This requires progress in technology, the development of improved pharmaceutical products,

> implementation of non-pharmaceutical techniques, improved industry regulations and intercompany cooperation" (Marine Harvest, 2018, p. 25).

To fully understand how the cited options of progress could stir continued industry growth, a basic understanding of the biological and technological foundations of salmon farming is required and hence given in the following section.

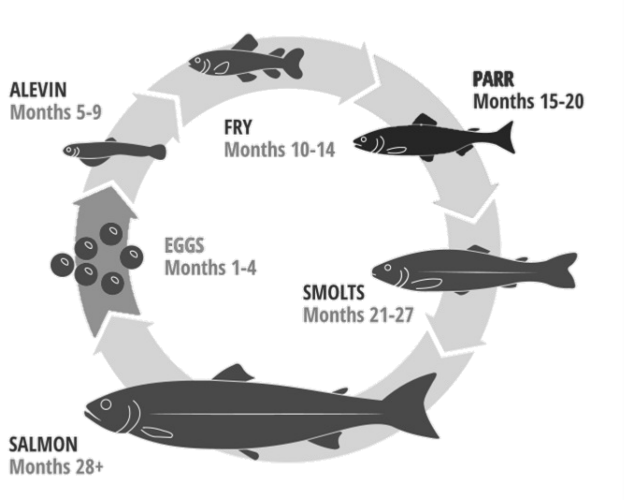
2.2 Biological & Technological Foundations

This section is meant to give an introduction into the biological and technological foundations of salmon aquaculture. First, the entire life cycle of a salmon in the wild will be sketched. The emphasis, however, will be put on the final two life cycle stages as these are the only stages relevant to salmon grow-out farmers. Next, the current technological level and the physical system will be introduced before the two future-oriented farming methods 'closed containment systems' and 'offshore aquaculture' will also receive their necessary attention.

2.2.1 The Salmon Life Cycle

Salmon are anadromous fish. Anadromous comes from the ancient Greek 'anádromos', a compound of 'aná' ("upward") and 'dromos' ("running"), and classifies salmon as migrating fish of which adult fish live in the sea (salt water) and migrate upriver into fresh water to breed (Oxford Dictionaries, 2019). In the wild, salmon eggs are spawned and hatched in fresh water. After several months in their natal river and undergoing three stages of development, alevin, fry, and parr, the fish go through a complex physical change known as the smoltification process to adapt to salt-water life. This includes "internal changes in the salt-regulating mechanisms of the fish" (Marine Institute, 2019). When this is complete, the fish are called 'smolts', migrate to the sea to mature and return to their natal river to reproduce after several months or years. Then, the life cycle, depicted in Figure 3, begins again (Marine Institute, 2019; Asche & Bjørndal, 2011).

Figure 3 – The Salmon Life Cycle



Adapted from Scottish Fish Farms, 2019

Based on this life cycle, Asche & Bjørndal (2011, p. 10) divide the biological processes of salmon aquaculture into the following four steps:

1. Production of broodstock and roe;
2. Production of fry (hatcheries);
3. Production of smolts;
4. Production of farmed fish.

Due to its characteristic of containing the most market-relevant decisions (Asche & Bjørndal, 2011) and being the most expensive stage (aquaManager, 2017), the grow-out phase, i.e. the production of farmed salmon in sea pens, constitutes the focus of this thesis. Steps 1 to 3 are not less important to the entire production process, but reproduction can just be considered a separate activity. It is a more biological emphasis that is inherent to these steps and since this thesis is the final paper to a master's degree in economics and business administration, the focus is put on Step 4.

Even though the biological details of Step 1 to 3 can be neglected, the timing is the only aspect that also significantly plays into the grow-out phase. As can be seen in Figure 3, the time periods of the different development stages can vary greatly and their length is dependent on several biological influence factors (such as genetic background, environmental conditions, etc.). Further, biological progress and discoveries could decrease the growth time until smoltification and speed up the salmon's gain in weight significantly. Normally hatching in January, salmon are usually released after 16 months in May but can meanwhile even be released in autumn after only eight months. “These smolts are at the lower end of the size range when released, but […] grow faster in the sea [and] will be larger than their cousins […] released the following May” (Asche & Bjørndal, 2011, pp. 10-11). Figure 4 illustrates the two most typical releases assuming hatching to occur in January.

Figure 4 – Atlantic Salmon Release Routines

Based on Asche & Bjørndal, 2011

A final biological detail of importance to the grow-out farmers is the fact that salmon lose their value when sexually maturing. Due to hormonal changes, sexual maturation has undesired effects on growth, health and flesh quality of farmed Atlantic salmon (Fjelldal, et al., 2012; Taranger, et al., 2010). Hence, early sexual maturation “is detrimental to fish health and quality when viewed from an aquacultural viewpoint” (Iversen, et al., 2016, p. 330) and the fish have to be harvested before spawning. Time of spawning differs a lot in farmed Atlantic salmon and sexual maturation accounts therefore for 50 % of downgrades in the primary processing of the fish (Michie, 2001). In consequence, salmon are usually not raised to marketable size for longer than two years (Asche & Bjørndal, 2011).

2.2.2 Current Technology: The Physical System

Having passed the smoltification phase and weighing between 60 and 110 grams, salmon spend the final grow-out phase in coastal, temperate marine waters in open net-pens (ONPs), also called ‘cages’ (Morton & Routledge, 2016). Even though other production methods exist, ONP farming in the ocean “has been the major technology for the on-growing portion of the production cycle” (Liu, et al., 2016, p. 2).

In a conventional marine ONP system, “salmon are reared in an open mesh net that is suspended within a rigid framework […] and that is buoyed at the surface and held in place by a system of anchors” (Ayer & Tyedmers, 2009, p. 363). Most often, a farm is comprised of multiple ONPs, either moored in close proximity or physically connected to form a large array (Norwegian Seafood Federation & Norwegian Seafood Council, 2011). ONP size has steadily increased and in 2010, new cages could measure up to 25 m in radius and 40 m in height which corresponds to a volume of 80 million liters (Asche & Bjørndal, 2011). Apart from the nets, the floating rings and the mooring systems, boats, feed barges, camera systems, feed distribution systems, and remote power systems also need to be invested in for the set-up of an ONP farm (Liu, et al., 2016).

The fact that flow-through ONPs “allow for free exchange between the farm and the surrounding environment” (SeaChoice, 2019) has raised concerns about the sustainability and environmental friendliness of this kind of farming system. Besides pollution from organic waste, the interaction between wild and (escaped) farmed salmon is the industry’s second main issue (Bjørndal & Tusvik, 2017). Due to the high density of fish that does not occur in nature, farmed salmon are exposed to conditions facilitating disease and parasite transmission. Additionally, the flow-through character of the ONP enables the exchange of pathogens between farmed and wild salmon. The most common parasite on farmed salmon is the sea louse (Asche & Bjørndal, 2011). “Sea lice cause damage to salmonids by eating their mucus, skin tissue and blood. This paves the way for other problems such as bacterial or fungal infections, and also affects the osmotic balance of the fish” (Institute of Marine Research, 2019). In consequence, sea lice became a significant cause of mortality in farmed salmon but also in wild populations (Institute of Marine Research, 2019; Costello, 2009). Further problems of genetic interaction between escaped, farmed and wild salmon are diverse and reach from fitness reduction to potential extinction through competition (Taranger, et al., 2010; McGinnity, et al., 2003; Einum & Fleming, 1997).

Finally, also the carbon footprint and the water consumption of Atlantic salmon production have been investigated. Due to the dependence on water conditions and suitable coastal sites, ONP production possibilities are geographically limited even though demand exists worldwide. Therefore, many markets have to be supplied by air freight which increases the environmental impact even though salmon has an extremely low carbon footprint and water consumption per kg edible meat in comparison to traditional animal protein production, as shown in Table 1.

Table 1 – Resource Efficiency & Environmental Impact of Animal Protein Production

	Salmon	Chicken	Pork	Cattle
Protein Retention	31%	21%	18%	15%
Energy Retention	23%	10%	14%	27%
Edible Yield	68%	46%	52%	41%
Feed Conversion Ratio (FCR)	1.1	2.2	3.0	4 - 10
Edible Meat pr 100 kg fed	61 kg	21 kg	17 kg	4 - 10 kg
Carbon Footprint kg CO2/kg edible meat	2.9	2.7	5.9	30.0
Water Consumption liter/kg edible meat	2,000 *	4,300	6,000	15,400

* The figure reflects total water footprint for farmed salmonid fillets in Scotland, in relation to weight and content of calories, protein and fat.

Adapted from Marine Harvest, 2018

All the abovementioned shortcomings of the current, predominant ONP system have raised the question: Is there a better way to farm fish?

2.2.3 Future Technology I: Closed Containment Systems

Given the aforementioned challenges, the industry is developing and working on lower-risk aquaculture methods and technologies for a few decades now. Since the free exchange between the farm and the surrounding environment constitutes the main source of concern, aquaculture research and development focus moved to closed containment systems (CCSs) (House of Commons of Canada, 2013). Those CCSs “describe aquaculture facilities on land or in the sea that have a separating barrier between the fish and the environment around the facility” (Bjørndal & Tusvik, 2017, p. 33).

The low-risk CCSs proved to solve indeed a lot of the environmental challenges of ONP systems (Kingdon, 2017). However, land-based Atlantic salmon farming also comes at a price. In their comparative economic analysis, Liu, et al. (2016, p. 11) showed that

> the carbon footprint of salmon produced in land-based closed containment water recirculating aquaculture systems that are using a typical US electricity mix based on fossil fuels is twice that of salmon produced in traditional open net pen systems, when delivery to the market is not included.

It seems obvious that land-based salmon farming would increase the consumption of fresh water substantially and hence decrease the salmon industry's competitive advantage over traditional meat production (see Table 1).

Further, land-based salmon farming also contains other elements of uncertainty. According to the International Salmon Farmers Association (2016, p. 13), land-based Atlantic salmon farms would require densities up to 80 kg fish per m^3 at their peak size compared to 25 kg for marine farms to be profitable. This would, however, have significant impacts on fish growth and health. Recently, researchers could also establish new scientific evidence for fishes' experience of pain (Jabr, 2018). In the future, this might lead to more density-restricting animal rights in aquaculture and even lower current density caps. Therefore, profitability remains the most severe obstacle for CCSs to take over the leading technology position. Coming back to the economic analysis of Liu, et al. (2016), they estimated a return on investment (ROI) of traditional ONP farming to be twice that of CCSs, making investment in corresponding production facilities more than unattractive (Hicks, 2016). Summarizing, while Atlantic salmon grow-out farmers might have CCSs as future technology already on their radar, traditional ONP systems will remain the predominant technology until the limitations of land-based solutions can be removed.

2.2.4 Future Technology II: Offshore Aquaculture

Besides CCSs, pioneering projects in Norway recently began to explore offshore farming facilities in order to be able to meet the rising demand also in the future (Flagstad & Tvedt, 2019). Thereby, a new production technology also known as offshore aquaculture has seen the light of day. According to Drumm (2010), offshore aquaculture

> may be defined as taking place in the open sea with significant exposure to wind and wave action where there is a requirement for equipment and servicing vessels to survive and operate in severe sea conditions from time to time. The issue of distance from the coast or from a safe harbour or shore base is often but not always a factor.

Due to the technical challenges mentioned in the definition above, offshore aquaculture is still making a relatively small contribution to the total aquaculture production volume. However, it bears the greatest potential for industry growth among all technologies currently under development according to the director of policy development and coordination for the

European Commission’s Directorate-General for Maritime Affairs and Fisheries, Ernesto Peñas Lado (Holmyard, 2016). The reason for this is space: “Offshore aquaculture opens up a plethora of new farming locations” (PwC, 2017). Therefore, the new production technology could contribute to a substantial increase in production volume as soon as it is fully developed.

Rethinking current technology started only a few years ago and in April 2016, the Norwegian government approved Norway’s first offshore aquaculture development project. This project combined marine engineering, cybernetics, and biology via a ‘big data’ approach. Also, it aimed at making use of Norway’s comprehensive technology knowledge base of developing oil and gas production units (Kongsberg, 2016). Designing the new cages and any associated infrastructure currently constitutes the most complex challenge as the exposure to rougher environmental conditions requires both more robustness and flexibility of any construction. In particular, high waves shift the focus to submergibility, which is only partly featured by current onshore installations. Concluding this concise digression into future technologies, in contrast to the CCSs, it is not profitability but mainly technological feasibility that will determine if offshore aquaculture can become a game changer of the industry or not.

2.3 Market Mechanisms

Having laid the biological and technological foundations, the salmon life cycle has different implications on production and price cycles that will be analyzed in the following two subsections.

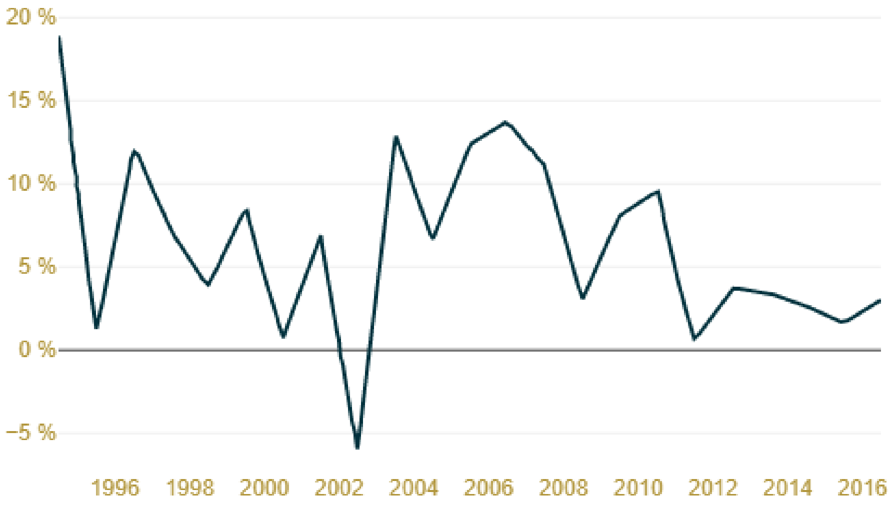
2.3.1 Production Cycles

As described in the 2.2.1 (The Salmon Life Cycle), the classical salmon life cycle usually lasts three years (Marine Harvest, 2018). In comparison to some other breeds like chicken, pigs, or cattle, this is a relatively long period (Lerøy Seafood Group, 2018). Regardless of whether they are raised conventionally or in operations such as ‘organic’, most other animals are slaughtered within half a year. As an example, broiler chickens in the EU “are slaughtered at an average age of 42 days” according to a recent EU publication (Directorate-General for Health and Food Safety, 2016, p. 1). The characteristic of salmon to grow comparatively slow and to take several years from hatching to harvestable size creates production cycles (Bjørndal & Tusvik, 2017). These cycles are known from other industries that also feature a significant time lag between the decision about the production volume and the moment when the production volume is ready for sale (Asche & Bjørndal, 2011). Asche & Bjørndal (2011, pp. 56-57) describe the development of these cycles as follows:

> A high margin gives a signal to increase supply, but due to the time lag in production, conditions may have changed significantly when the increased output reaches the market. This often leads to over-investment, causing production to increase too much, and prices may fall for a time to, or even below, the cost of production. The low margins will then be a signal to reduce production, which again takes time, and production will often be reduced too much, giving rise to a new period with high margins.

Figure 5 shows the cycles by the example of the Norwegian year-on-year smolt release. In general, industry growth has been positive during the displayed period. However, the described production cycle scenario can be identified very well and the volatility in the smolt release illustrates the over- and under-investments described by Asche & Bjørndal (2011).

Figure 5 – Year-on-Year Growth in Smolt Release in Norway, 1994 – 2016

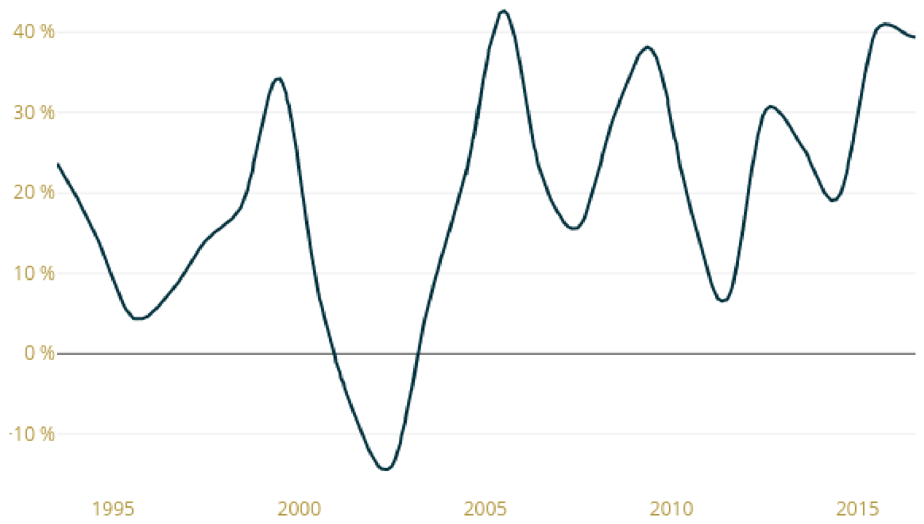


Adapted from Lerøy Seafood Group, 2018

2.3.2 Price Cycles

The previously described production cycles directly affect the market price and vice versa. The fluctuating earnings before interest and taxes (EBIT) margin in Figure 6 does not exactly reflect the fluctuations in the market price. However, it serves as a good indicator since production costs are rather constantly rising than fluctuating (Mugaas Jensen, 2018) and hence cannot explain the extreme variations in the EBIT margin. A recent report by EY (2018, p. 19) suggests a correlation coefficient of +0.59 % between salmon prices and earnings before interest, taxes, depreciation and amortization (EBITDA) margins.

Figure 6 – EBIT Margin Norway, 1994 – 2016



Adapted from Lerøy Seafood Group, 2018

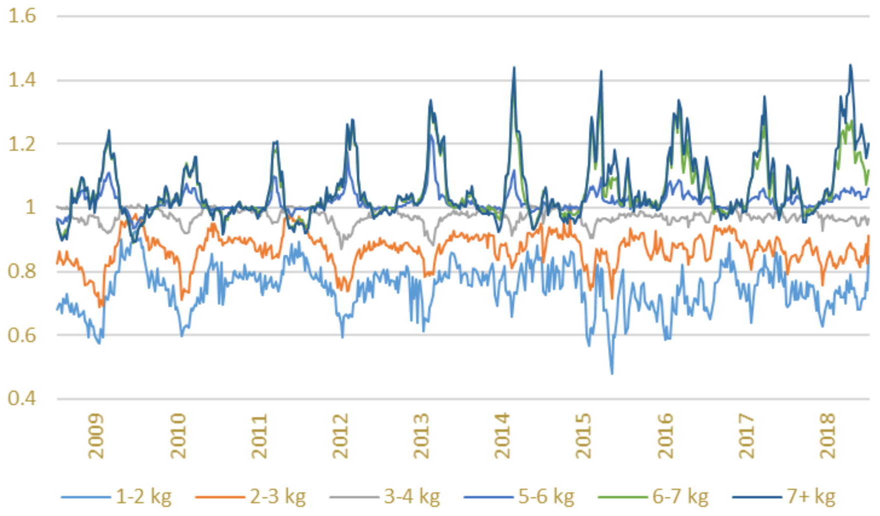
In addition to those 3-year-lasting cycles, there are also patterns in the relative price for different sizes of farmed salmon, as detected by Asche & Guttormsen (2001). These patterns can be explained as follows: Salmon is not a homogeneous good and various quality attributes such as color, marbling, fat content, and size influence its market price. In particular, differences in size have a significant impact on the price per kg which is why salmon are divided into different weight classes 1-2 kg, 2-3 kg, 3-4 kg, etc. (Nasdaq, 2019). As smaller sizes limit the processing possibilities, higher weight classes tend to be also priced higher (Asche & Bjørndal, 2011). Now, the dependence upon the relatively fixed periods of release displayed in Figure 4 implies that salmon grow in cohorts. Hence, "different fish farmers are likely to have a similar distribution of different sizes of fish over time" (Asche & Guttormsen, 2001, p. 235). Therefore, the price differences are not constant but vary throughout the year in yearly recurring patterns. Asche & Bjørndal (2011, p. 114) illustrate this phenomenon as follows:

> There will be relatively moderate quantities of small salmon in the winter months because salmon transferred to the sea in autumn are not large enough to sell, and those that were transferred to sea the previous spring are already larger. In this period the price for the small salmon is therefore comparable to that of the larger

> salmon. However, in the summer months when the small salmon are abundant, it fetches a relatively low price. Similarly, in order to avoid large salmon becoming sexually mature in autumn, most are sold during summer. The availability is therefore limited during autumn, and therefore large fish fetch a relatively high price in this period.

Figure 7 illustrates this volatility graphically by setting the prices of the displayed weight classes (1-2 kg, 2-3 kg, etc.) into relation with the 4-5 kg weight class price. Following the example of Asche & Guttormsen (2001), Figure 7 was built upon the most recent (inflation-adjusted) prices of the last ten years from the NASDAQ Salmon Index (NQSALMON). Without any doubt, Figure 7 confirms the continued existence of the price patterns found by Asche & Guttormsen (2001) almost two decades ago.

Figure 7 – Relative Prices by Weight Class (4-5 kg = 1), 2009 – 2018



Based on Nasdaq, 2019

To conclude Section 2.3, salmon grow-out farmers must take into consideration long-term as well as short-term price cycles with respect to their production planning. In terms of long-term cycles, the literature suggests that price signals seem to be overestimated and that the forecast of future demand is difficult. The overestimations can be observed both as a too positive as well too negative interpretation of the current margin and do therefore not serve as an explanation for the investment behavior-paradox found by Pettersen Aubell & Haugen Hamarsland (2018). In terms of short-term cycles and the dynamics in the relative price relationships, the price per kg for salmon of weight class x at calendar week y needs to be considered. As far as the elaborated biological constraints allow, this leaves grow-out farmers with two important production planning decisions: “1) when to transfer the juvenile fish to the pen and 2) when to harvest the fish” (Guttormsen, 2008, p. 402).

2.4 The Production Process

As shown in the previous section, salmon grow-out farmers need to consider well-known market mechanisms to find the optimal points in time of when to start and end a rotation. In between, growth maximization and biomass optimization are the second of the two large pillars in the farmers’ yield management. Biomass, in this context, is the product of the number of fish and the weight of the fish (Guttormsen, 2008). Maximizing growth and optimizing biomass, salmon grow-out farmers have the opportunity to influence a variety of decision variables. Salmon aquaculture literature covered eight key decision variables that the following subsections will investigate in the sequence of their occurrence in the salmon life cycle:

1. Smolt Quality
2. Smolt Release
3. Feeding
4. Environmental Conditions
5. Stocking Density
6. Salmon Lice
7. Loss of Fish
8. Harvesting & Slaughtering

2.4.1 Smolt Quality

As stated earlier, the focus of this thesis is on the grow-out phase and the economic decisions made by salmon grow-out farmers. Therefore, the biological background of broodstock and smolt production is not explained in detail here. Dependent on the business, salmon grow-out farmers buy in their smolt from specialized smolt farms, or even have vertically integrated this process into their own operations (Asche & Bjørndal, 2011). Either way, the choice of smolt is the first economically relevant decision made by any grow-out farmer with regard to the salmon life cycle. Hence, smolt quality is the first critical aspect for the success of the final production.

The term ‘quality’, in this case, mainly refers to a variety of commercially relevant traits whose manipulation enables salmon grow-out farmers to reduce their production costs. Generally, this goal is pursued by both improving the growth performance and reducing the mortality of the fish. Growth performance is tried to enhance by improving the feed conversion efficiency as well as temperature, light, oxygen, and salinity sensitivity (see 2.4.3). Mortality is tried to reduce by deferring sexual maturity and improvements in stress, disease, and salmon louse resistance.

Additionally, fillet quality (in particular flesh color and fat content) is also tried to optimize in the systematic breeding programs (Stofnfiskur, 2019). Those “are of great importance in improving desirable traits in Atlantic salmon and for the growth and economic viability of the industry” (Asche & Bjørndal, 2011, p. 56). It is important to note that there exists a trade-off between the number of traits and the response to each trait. Simply put, adding additional traits to a breeding program leads to reduced response to each trait. Finally, the growth and the development of the industry, meanwhile, enable salmon grow-out farmers to select their individual and tailored breeding strategy (i.e. mix of traits) when engaging in a long-term relationship with their smolt breeding facility (Asche & Bjørndal, 2011).

2.4.2 Smolt Release

Upon having chosen the smolt and its traits, salmon grow-out farmers are confronted with the decision of when and how much smolt to release into their ONPs. As analyzed in Section 2.3, this decision will have a considerable influence on the company’s profits.

How much to produce depends mainly on the future market price that is expected for the time when the salmon reach marketable size. Besides, licenses put a cap on production capacities. These will, however, be investigated in more detail in subsection 2.5.3 – MAB Regime.

The timing of the release is also a complex decision as “smolt released at different times of the year experience different environmental conditions” (Lysfjord, et al., 2004, p. 191) that have a direct impact on their growth behavior as well as mortality. Traditionally, smolts were transferred from fresh water to sea water in spring as this also corresponds to the natural process in the wild. By means of manipulation of photoperiod (which is the physiological reaction of organisms to the length of day and night), salinity and temperature, the industry managed to produce off-season smolts available for transfer earlier or later than the traditional April-release (Melo, et al., 2014). Thus, biological constraints of smolt release could be reduced to a large extent due to biotechnological advancement and salmon grow-out farmers are given higher flexibility in their release decision.

Despite this flexibility, the transfer of the fish to the OPNs remains a sensitive process and losses in Norwegian salmon production subsequent to the sea water transfer still amount to around 16 %. The production of “larger and more robust post-smolt in recirculating aquaculture systems (RAS) or semi-closed facilities in the sea may reduce mortality and shorten the production time in the sea and thus reduce the problems with sea lice” (Ytrestøyl, et al., 2015a, p. 39). This technology is, however, not fully sound yet and remains under development (see also 2.2.3 – Future Technology I: Closed Containment Systems).

2.4.3 Feeding

“Feed represents about half of the total production cost for salmonids, and is, as such, a key focus area in the industry” (EY, 2018, p. 19). In the wild, carnivorous fish such as Atlantic salmon eat other fish, which is why they rely upon high protein levels in their diet, usually obtained from animal sources (Huntington & Hasan, 2009).

Their feed includes fish oils, fishmeal, and animal proteins but also plant proteins, minerals, and vitamins (NOAA Fisheries, 2019). In particular, the fishmeal provides the low levels of essential fatty acids that are required for salmon growth and serves as an almost optimal cost-effective, convenient and highly digestible feed (Tacon & Metian, 2008). With their favorable nutrient compositions, fishmeal and fish oil have historically been the two most important ingredients in salmon feed (Shepherd, et al., 2017) and added up to 30 – 50 % of the feed (NOAA Fisheries, 2019). However, these ingredients are not necessarily required and research “has accelerated progress toward reducing fishmeal and fish oil use in aquaculture feeds while maintaining the important human health benefits of seafood consumption” (NOAA Fisheries, 2019).

Despite those reductions, there exists an ongoing discussion on the extent to which salmon aquaculture can be described as sustainable. The industry is challenged on a broad range of sustainability issues (Allsopp, et al., 2008; Deutsch, et al., 2007), but in this case, (un)sustainability refers to overfishing and the ‘net loss of protein’. As described, farming and feeding carnivorous species used to involve substantial inputs of wild fish. A decade ago, Naylor, et al. (2009) saw still 5 kg of wild fish to be used as feed to produce 1 kg of salmon, also known as fish in – fish out (FIFO) ratio. Data reporting FIFO ratios of under 1 often refer to the aquaculture as a whole (BioMar, 2017). Since the FIFO ratios for omnivorous fish such as carp or tilapia represent only a fraction of the FIFO rate for salmon aquaculture, those numbers are neither representative nor helpful. In any case, the focus of this thesis lies on the economic decision making rather than on environmental topics. Hence, the managerial aspects of feed require some more investigation.

Salmon are fed dry pellets that usually contain about 70 % vegetable ingredients and 30 % marine raw materials like fishmeal and fish oil (Salmonfacts, 2019; Ytrestøyl, et al., 2015b). Much research has been carried out on the effect of dietary composition and Shearer (2001) provides an overview of how variations in protein, fat, fatty acids, carbohydrate, ash, and dietary supplements and biochemical regulators influence fish composition (carcass, muscle, lipid, protein, body weight, etc.). For the abovementioned sustainability reasons as well as in favor of cost reductions, the industry started to investigate the effects of replacing dietary fish oil with vegetable oils. First experimental studies demonstrated the possibility to fully replace fish oil and reduce the use of fishmeal without any detrimental effects on growth or feed conversion (Burr, et al., 2012; Bell, et al., 2010; Torstensen, et al., 2008). Since the pellets are, however, produced by a largely consolidated salmonid feed industry where the largest five companies generated about 90 % of the subsegment's revenue in 2016 (EY, 2018), competitive cost and growth advantage through individualized feed seems limited and cannot be detected in the literature, either.

In terms of room for maneuver, the feeding regime leaves the greatest scope of influence to salmon grow-out farmers. In more detail, they can influence the feeding rate, meal frequency, time of feeding, and fasting (Shearer, 2001). Feeding practices include hand feeding as well as automatic feeding systems equipped with video monitoring (FAO, 2019c). "Maximum growth is usually obtained when the fish are fed until the point of satiation" (Einen, et al., 2007, p. 201). Measuring satiation and feed intake is enabled by feeding surveillance systems, sensors, or collection of feed waste and has a significant positive effect on feed utilization (Einen, et al., 2007). Feed intake was observed to be higher during daylight (Fraser & Metcalfe, 1997) even though the effect of meal-time remains unclear (Bolliet, et al., 2000; Boujard, et al., 1995).

Summarizing, the topic of feeding is very complex and contains a lot of interacting factors such as feed composition, feeding technology, and feeding time. Taking into account all of them requires a large degree of knowledge and experience and more practical insight is required and expected from future research.

2.4.4 Environmental Conditions

Once released into the sea, salmon are not only fed differently but also exposed to a range of environmental conditions that can only partly be influenced by the grow-out farmers. Additionally, there exist large variations in the sea-water temperature and photoperiod along the Norwegian coast as well as large annual variations within certain geographic locations (in particular in Northern Norway) (Lysfjord, et al., 2004). These differences influence the entire grow-out process even though about 70 % of all Norwegian grow-out farms lie in “areas with climatic conditions similar to those around Bergen” (Asche & Bjørndal, 2011, p. 13).

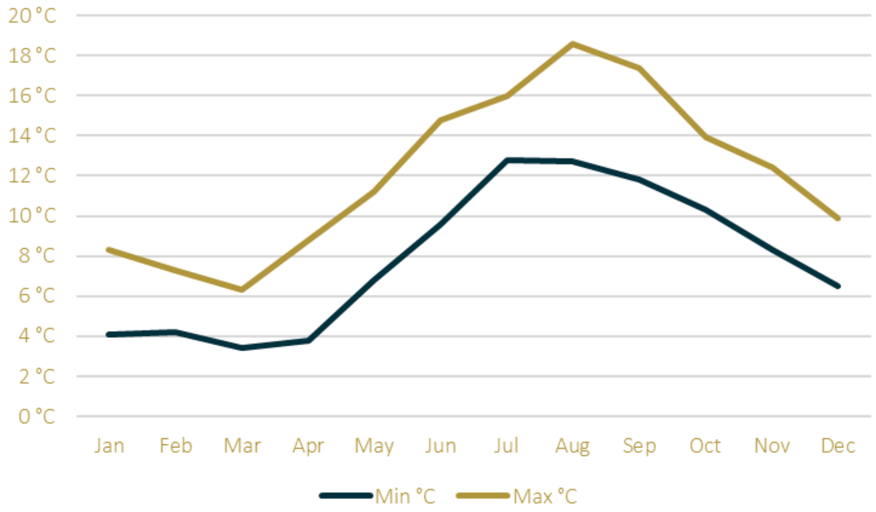
Sea-Water Temperature

Investigating the water conditions first, sea-water temperature “is one of the essential parameters for the growth of the fish because temperature affects all metabolic processes in fish” (Lorentzen, 2008, p. 418).

Along the Norwegian coast, sea-water temperature normally lies within a range of 5 to 20 °C. Even though the fish can survive within this entire range, salmon prefer temperatures between 13 and 17 degrees Celsius (°C) (Wallace, 1993). Outside this range, the growth of the fish is negatively affected through either reduced feed intake or increased stress levels (Lorentzen, 2008). More recent analyses suggest that growth is most efficient at lower temperatures around 13 °C (Hevrøy, et al., 2013). This coincides with the average monthly Bergen sea temperatures, displayed in Figure 8, and the findings by Asche & Bjørndal (2011) who observed most of the growth in late summer and early autumn.

Due to higher temperatures, salmon grow-out farms in southern Norway tend to experience higher growth rates than average while the opposite applies to northern Norwegian farms that have to deal with below-average temperatures (Asche & Bjørndal, 2011). On the other hand, temperatures above 17 °C impact fish growth negatively (Hevrøy, et al., 2012) where temperatures above 20 °C even lead to a physiological breakdown (Lorentzen, 2008). As a result, salmon grow-out farmers in southern Norway can even experience bimodal growth curves in warm summers (Asche & Bjørndal, 2011).

Figure 8 – Monthly Average Max / Min Sea-Water Temperatures in Bergen, Hordaland



Adapted from World Sea Temperatures, 2019

Generally, it can be stated that the temperature tolerance of salmon increases with age (Helland, 2018). This implies that keeping the fish longer in controllable water conditions could also further enhance growth and survival rates (Elliott & Elliott, 2010).

As a final remark regarding temperature, climate change is expected to also increase sea temperature in the Northeast Atlantic along the Norwegian coast (Helland, 2018; Elliott & Elliott, 2010). In his analysis, Lorentzen (2008, p. 431) predicts a linear positive effect on the gross present value (GPV) for firms located in northern Norway for temperature increases up to 5 °C. For further temperature increases, he predicts the effect still to be positive, even though diminishing. These environmental changes could lead to a value increase in the production licenses for northern Norwegian regions and should be kept in mind for the further analysis of the grow-out farmers' investment behavior.

Oxygen

Another factor also affecting salmon growth is the density or level of dissolved oxygen in the water. More than a quarter-century ago, Crisp's (1996; 1993) analysis showed the special sensitivity of Atlantic salmon to reduced levels of oxygen.

Taking up again the positive effect of relatively warm sea temperatures on the growth of the fish, it is noteworthy that with higher temperatures, the density of oxygen generally decreases (Lorentzen, 2008). Thus, there exists a negative relationship and hence trade-off between sea-water temperature and density of oxygen.

In their study, Johansson, et al. (2006) detected significant temporal and spatial variations in the oxygen level in sea cages at a fjord site with dependency on temperature, photoperiod, and density of fish. In addition to the negative temperature-oxygen relationship, they also detected reduced oxygen levels as day length got shorter towards the end of the year as well as a negative correlation between the density of fish and oxygen conditions.

Next to the factors that have already been mentioned, the level of oxygen mainly depends on (the vertical distribution of) water current velocities. Since photosynthesis of algae and the mixing of atmospheric oxygen do not suffice to cover the oxygen needed by an entire grow-out farm, oxygen requirements must be met by water currents (Johansson, et al., 2007). These, again, depend on different factors such as fresh-water runoff, tidal movements or wind and are difficult to predict (Wildish, et al., 1993).

To solve this problem, the industry successfully developed aeration and oxygenation systems in order to be able to balance the level of dissolved oxygen at each site and throughout each ONP (Berillis, et al., 2016).

Salinity

As part of the smoltification process, Atlantic salmon also develop salinity tolerance (McCormick, 1996) which likewise can be described as “the development of mechanisms for osmoregulation in both fresh water and sea water” (Parry, 1960). This process is essential as Atlantic salmon show a clear correlation between size and major life history events, including smoltification (Graham & Harrod, 2010).

In contrast to temperature and oxygen, salinity does not correlate with any of the other environmental influence factors but depends on “rates of precipitation, evaporation, freezing and melting” (Natural Environment Research Council, 2019). These might be influenced by climate change which is supposed to increase, for example, melting and riverine runoffs and thereby decrease salinity in coastal sea water to a certain degree (Holt, et al., 2010). However, the short and medium-term influence of this factor can be supposed to be neglectable.

Nevertheless, lower sea-water temperature as well as higher salinity were shown to both have a negative influence on the osmotic balance of Atlantic salmon (Sigholt & Finstad, 1990; McCormick, et al., 1989). Even though both factors do not depend on each other, the experiments by Handeland, et al. (1998) indicated that reduced salinity (such as in brackish waters) could make up for some of the osmotic disturbance caused by lower and decreasing temperatures mostly experienced by out-of-season smolts transferred to the sea from October to April. Therefore, reduced salinity is thought to support the growth and survival of out-of-season smolts. Apart from that, “the physiological response of salmon smolts acclimated to brackish water (28 ‰), e.g. in a fjord site, is not different from that of smolts acclimated to full strength seawater (34 ‰), e.g. in more exposed coastal areas” (Handeland, et al., 1998, p. 300).

Light

A final environmental factor is light. Several studies have shown the effects of light as both a modulator of growth and a timer of development (especially sexual maturation) (Bromage, et al., 2001; Boeuf & Le Bail, 1999; Björnsson, et al., 1994).

Daylight duration is determined by the natural photoperiod which varies a lot along the Norwegian coast and across seasons in the course of the year, especially in northern Norway (Friborg, et al., 2012). Therefore, the fish are exposed to continuous light, which affects their perception of the season and circannual cycle (Iversen, et al., 2016). In doing so, salmon growth is sped up and sexual maturation is inhibited artificially (Porter, et al., 2001; Boeuf & Le Bail, 1999). The effectivity of the use of artificial light, however, also depends on the seasons, as Glebe’s (2012) analyses show:

> Increasing the perceived day length of farmed Atlantic salmon through exposure to artificial light 24 hours a day in the autumn results in significant increases in their overall growth by the end of May and significantly lowers the sexual maturation rates of both males and females. Artificially increasing the day length starting in February does not have the same effect on reducing maturation rate, and outcomes are more unpredictable.

Summarizing the scope of influence for the environmental factors temperature, oxygen, salinity, and light, only the level of dissolved oxygen and the photoperiod can be manipulated directly also in the ONPs. Usually, ONPs are lacking in both, which is why additional oxygen, as well as additional light are usually imposed on the fish for improved aquacultural growth conditions. Under the current production technology, this is not possible for sea-water temperature and salinity. Both, however, can be ‘chosen’ indirectly by varying the decision of when and where to release the smolts.

2.4.5 Stocking Density

Stocking density in aquaculture is “the weight of fish kept in a given volume of water” (RSPCA, 2019). The impact of stocking density on the growth and survival of artificially reared Atlantic salmon has been investigated intensively. From the beginnings of the industry, it was found that higher densities depress the growth rate of the fish (Refstie & Kittelsen, 1976). According to the current Norwegian legislation (akvakulturdriftsforskriften), stocking density is limited to up to 200,000 individual fish per unit (§ 47a) and 25 kg fish per m^3 (§ 25) (Nærings- og fiskeridepartementet, 2008).

Nevertheless, maximum stocking densities of up to 20 kg m^{-3} are usual (FAO, 2019d) for good reasons. Turnbull, et al. (2005) found reduced fish welfare with increasing stocking density from densities of 22 kg m^{-3}. When comparing wound healing at densities of 20 kg m^{-3} and 100 kg m^{-3}, Sveen, et al. (2018) detected that the higher fish density enhances immune responses and delays tissue repair. Further, stocking densities over 30 kg m^{-3} significantly increase the stress level of the fish and are also negatively correlated with the feed conversion rate (FCR) which finally leads to reduced growth (Wang, et al., 2019). Problems such as fish becoming aggressive towards each other that could be observed for very low densities (RSPCA, 2019) are normally not relevant to salmon aquaculture as salmon grow-out farmers usually seek to utilize their production capacities to the full.

In particular with new technologies, stocking density remains a key issue. As indicated in 2.2.3 (Future Technology I: Closed Containment Systems), land-based Atlantic salmon farms would require densities up to 80 kg m^{-3} at their peak size to be profitable (International Salmon Farmers Association, 2016, p. 13). Calabrese, et al. (2017, p. 363), however, recently tested the density limit for post-smolt Atlantic salmon and found significantly reduced specific growth rates (i.e. percentage increase in size per day) from stocking densities of 50 kg m^{-3} and above. Concluding, the chosen stocking density can be described as an elementary factor with an influence on the growth performance as well as mortality of the fish. Hence, the grow-out farmers’ choice on how much fish to raise in each ONP is of substantial economic importance.

2.4.6 Salmon Lice

Since the high stocking densities in salmon aquaculture provide better conditions for parasite transmission and growth, infection of the fish with salmon lice (Lepeophtheirus salmonis), became the most severe health challenge in salmon aquaculture today (Torrissen, et al., 2013).

The small crustacean attaches itself to the salmon and feeds on mucus, blood and skin cells (Mordue & Birkett, 2009). This makes the salmon more susceptible to infections and osmotic disturbances, hence, increasing the mortality of the fish (BioMar, 2019). While the extent to which salmon lice originating from grow-out farms also negatively affect wild salmon populations remains a matter of debate (Torrissen, et al., 2013), there exists consensus that they exert the greatest economic impact of all parasites affecting aquaculture (Overton, et al., 2018).

Therefore, the industry encounters the problem with a broad range of preventive and control measures that can be divided into chemical treatments (e.g. with azamethiphos, cypermethrin, deltamethrin), hydrogen peroxide (H_2O_2) treatments, thermal as well as mechanical delousing (Grefsrud, et al., 2018). Historically, the threats of salmon lice were counteracted by a continuously increasing variety of chemical products. Over the years, the lice developed resistance and, therefore, the industry was forced to change perspective and proceed into a new way of thinking (Veterinærinstituttet, 2016).

Analyzing the different kinds of measures, Overton, et al. (2018) could observe a recent and rapid paradigm shift from chemotherapeutant to thermal and mechanical measures where thermal and mechanical measures made up more than 74 % of the treatments in 2017 compared to less than 19 % between 2012 and 2015. Either way, measures that require the fish to be taken out of the ONP involve persistently high percentages of mortality subsequent to the treatment of the fish. In particular, thermal treatments exhibit mortality rates of up to 31 %, mechanical treatments up to 25 %. Therefore, the industry is in search of other more fish-friendly and sustainable solutions.

Wrasse (Labridae) as cleaner fish were tested as an alternative but tended to become inactive in winter. Lumpfish (Cyclopterus lumpus), however, continue to feed on sea lice also at low temperatures, which is why their commercial production rapidly increased from a few thousand in 2010 to well over 30 million in 2016. The most severe obstacle of a further extension of production to meet the global industry needs of around 50 million fish is sustainability. To meet this demand, lumpfish production needs to overcome its reliance on the capture of wild broodstock and develop its own aquaculture in the years to come (Powell, et al., 2018).

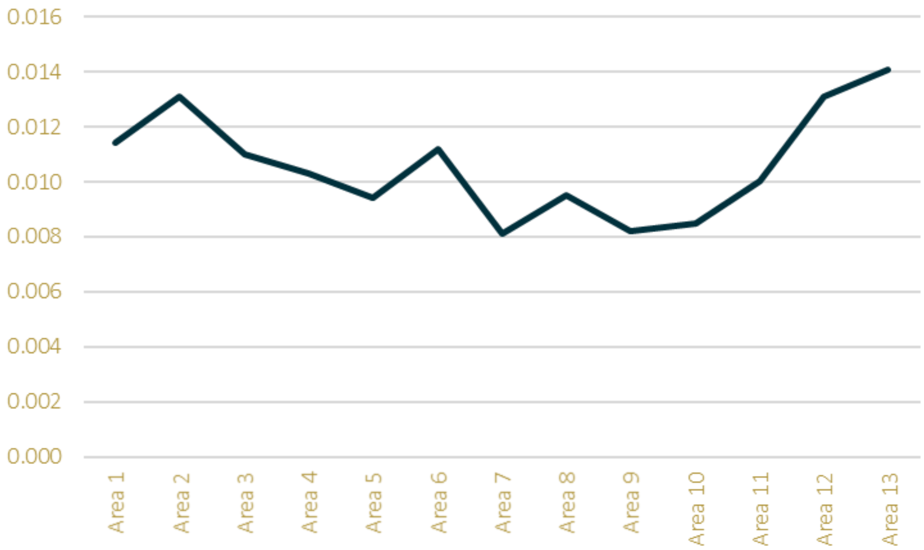
2.4.7 Loss of Fish

For the economy and resource efficiency of the industry, losses in production are important to be investigated. From an economic perspective, the loss of farmed Atlantic salmon at sea due to either mortality or escape is substantial and represents a significant challenge for salmon aquaculture (Aunsmo, et al., 2008).

Mortality

The country-wide average mortality currently lies at around 20 %, which corresponded to 53 million fish in 2017 (Trana & Moen Nilsen, 2018). This is a significant percentage and viewed critically by animal welfare organizations, authorities, politicians, consumers, and salmon grow-out farmers alike (Skonnord, 2018). Mortality, however, varies greatly between different production areas and grow-out farms and reaches from only 3.5 % for the best farms to a loss of 43 % for the worst (Trana & Moen Nilsen, 2018). The average monthly mortality per production area based on the Directorate of Fisheries' data set is displayed in Figure 9.

Figure 9 – Average Monthly Mortality of Atlantic Salmon in Norway, 2015 – 2016



Analyzing mortality reveals a broad range of possible reasons. Mortality over time, environmental conditions, season, fish size, stocking density, year and time of release, but also differences in working methods, culture and equipment all may affect the mortality of Atlantic salmon in a specific ONP (Grefsrud, et al., 2018; Guttormsen, 2008). In terms of diseases, pancreas disease (PD) and infectious salmon anaemia (ISA) constitute the most significant viral diseases. Additionally, Yersiniosis, a bacterial disease, has developed into an increased challenge in mid-Norway (Veterinærinstituttet, 2018).

Unfortunately, there exists very few research on cause-specific mortality and available data are rather treated as crude mortality without differentiating between different causes of death (Aunsmo, et al., 2008). Nevertheless, the choice of delousing measure is usually declared the most significant and most influenceable factor in explaining and reducing fish mortality (Trana & Sandmo, 2018; Veterinærinstituttet, 2018) and the enormous differences between the farms support this point of view.

Escape

Next to mortality, the second cause of loss of fish is escape. Escapes from salmon grow-out farms occur from ONPs as both repeated small losses as well as through large-scale episodic events (e.g. storm damage) (SalmonBusiness, 2018a; Thorstad, et al., 2008). Just like the mortality data, salmon grow-out farmers are required to also report this kind of loss to the responsible Norwegian authorities – the Norwegian Directorate of Fisheries and the Norwegian Food Safety Authority (Nærings- og fiskeridepartementet, 2008).

For 2018 and 2019, the numbers are still continuously updated, but in 2017, the number of escaped Atlantic salmon has dropped to record-breaking 15,559 fish. In contrast, the average number of escaped Atlantic salmon has been 341,688 from the beginning of record keeping in 2001 until 2016 with a maximum of almost 1 million escaped fish in 2006 (Fiskeridirektoratet, 2019a).

The reported numbers should, however, be taken as minimum estimates and looked at with a particularly critical eye. Naturally, salmon grow-out farmers have an incentive to underreport the cited numbers in order to conceal operational mismanagement (Grefsrud, et al., 2018). Consequently, the magnitude of unreported escapes remains unknown and "information on low-level leakage and escapes from freshwater hatcheries remains uniformly poor" (Thorstad, et al., 2008, p. 3). A simulation of escape events by Skilbrei, et al. (2015) revealed that numbers between 2005 and 2011 might have been 2 to 4 times higher than reported. Thorstad, et al. further reveal that "numbers of farmed salmon escaping to the wild are large relative to the abundance of their wild conspecifics" (2008, p. 3).

Despite this fact and the suspected underestimations, the economic relevance of fish escape for salmon grow-out farmers remains relatively low compared to the numbers of fish lost through mortality.

2.4.8 Harvesting & Slaughtering

Harvest comes at the end of the production cycle of every animal farmed for food and the final decision of the production process that has to be made by the salmon grow-out farmers refers to how and when to harvest the fish. Even though methods of harvesting vary between different grow-out farms, most farmers harvest their fish from 2 kg upwards (FAO, 2019d) and adhere to the following pattern.

Like in the wild, Atlantic salmon are usually exposed to a period of starvation before harvesting in order to “obtain complete gut evacuation and a clean digestive tract, to ensure good water quality (e.g. minimize excretion of ammonia) and to reduce metabolic rate, physical activity, hierarchy and stress during transportation” (Waagbø, et al., 2017). Following this, the fish are crowded in their ONPs by using sweep nets (The Fish Site, 2008). Then, they are either slaughtered directly on the side of the ONPs or transported alive in the well or tank of a well-boat from the ONPs to centralized processing plants (Erikson, et al., 2016). Upon anaesthetization, for which a variety of methods exists, bleeding is carried out through rapidly cutting the gill arches of the fish. Then, their flesh temperature is reduced to approximately 3 °C by immersing them in iced water. Subsequently, they are gutted, washed, chilled, graded and packed on ice upon which they can be frozen for sale (The Fish Site, 2008).

As detected in the previous subsections, the salmon aquaculture industry is confronted with some serious sustainability and animal welfare concerns. Quite contrary to other links in the production, humane slaughtering techniques take a forerunner role in comparison to other fish farming industries (Lines & Spence, 2014). Throughout its history, the industry has seen significant improvements, among them the banning of carbon dioxide (CO_2) as a stunning method (Mejdell, et al., 2011). Additionally, slaughterhouses are strictly monitored by the FSA and obliged to follow the Aquaculture Operations Regulations (Salmonfacts, 2016).

Providing a preview into future developments, the description of the harvesting and slaughtering processes already indicates substantial potential for automation. Apart from reduced costs, increased product quality and safety constitute the main advantages. Anticipating this, the Norwegian salmon industry set up the project ‘Industrialized slaughter of Atlantic salmon: Direct processing and superchilling’ in order to foster collaboration between industry and researchers on this specific topic. Within the timeframe of the project

(2013 – 2019), a multi-disciplinary research and development team works on the increased efficiency and sustainability of tomorrow's salmon industry (Forskningsrådet, 2013).

Besides the purely technical and procedural aspects of how to harvest and slaughter the fish, the much greater economic potential lies in the question of when to bring the fish to the market. Each farmer frequently has to evaluate "whether to harvest now to capture a known price, or to continue to feed to deliver a larger salmon at an unknown future price" (Forsberg & Guttormsen, 2006, p. 184).

Until about 14 years ago, salmon was to a large extent sold on spot markets as there did not exist any formalized derivative market and participants were consequently not able to hedge prices (Forsberg & Guttormsen, 2006). In 2005, however, Fish Pool ASA was established as "the global exchange for price hedging of fish and seafood products" (Fish Pool, 2019). Since then, the financial trading of cleared and future contracts is also possible in the industry.

The volatile salmon prices that were described previously make the timing of harvesting a decisive factor for the profitability of each farming business. More concretely, it is upon the grow-out farmers to decide whether to market the fish at a current, known price or to continue to feed them and sell them later at a higher weight and yet unknown price (Forsberg & Guttormsen, 2006). "While the feed costs may imply that it is optimal to harvest the fish earlier than otherwise, the harvesting costs work in the opposite direction. The net result is an empirical question" (Asche & Bjørndal, 2011, p. 169). The time of harvesting is not completely up to the grow-out farmers for two main reasons. First, their overall production capacity is limited by the MAB regulation (explained in the following section). Second, salmon growth is also biologically limited (especially due to sexual maturation). Nevertheless, forecasting of prices takes a key role in order to harvest the right fish at the right time.

As a final aspect with regard to harvesting, Asche & Bjørndal (2011) further introduce selective harvesting, which is the spreading of the harvest over time and harvesting the largest fish from an ONP first. Thereby, farmers can react to differences in growth and seasonal prices and spread the financial risk. As a method to also spread the harvesting workload, it is most important for on-site harvesting farms. However, this technique, to which Asche & Bjørndal (2011, p. 200) also referred as 'high-cropping', does not seem to be a common practice in the industry and does not receive much attention in academic salmon aquaculture literature.

2.5 Norwegian Salmon Aquaculture Regulation

Historically, the production process investigated in the previous section but also the entire Norwegian aquaculture industry has been regulated in various ways and this section will provide a comprehensive (historical) overview. Over the years, industry regulation focus shifted from ensuring local ownership and employment to today's focus on sustainability and the adherence to environmental standards. First, sustainability was tried to obtain by limiting the farmer's production volumes through the MAB regulation. In the last years, also environmental issues began to receive attention from the Norwegian legislature. In this regard, the Production Area Regulation (produksjonsområdeforskriften) constitutes the newest introduction on behalf of the Norwegian aquaculture authorities.

2.5.1 Focus on Local Ownership & Employment from 1973 to 1996

When salmon aquaculture overcame its infancy, the first set of regulations in Norway was introduced with the beginning commercialization of the industry in 1973 from which on every salmon grow-out farmer needed a license to legally operate his farm (Asche & Bjørndal, 2011). Aiming at strengthening coastal and fjord communities by emphasizing local ownership and employment, each company was also allocated only one license (Schwach, et al., 2015). This license was, however, given out for free (Lysø, 1977). Furthermore, authorities were also given the power to establish requirements regarding product quality and animal health (Norwegian Seafood Federation & Norwegian Seafood Council, 2011).

The Norwegian Official report from 1977 was proved right in arguing that the country's environmental characteristics are ideal for the development of extensive aquaculture and the industry flourished (Lysø, 1977). In 1978, the attraction of the industry became so strong that a temporary ban on new licenses had to be introduced. Consequently, Norway adopted a new Aquaculture Act in 1981 and continued its endeavors to geographically spread the farms along its entire coast (Fiskeridepartementet, 1979-80). Whereas until 1980 70 % of the total volume was produced in Hordaland, Møre og Romsdal, and Sør-Trøndelag counties, the four national licensing rounds in the 1980s prioritized the three northernmost counties of the country such that the farms extended along the entire coast subsequent to the last round in 1989.

In 1983, first diseases broke out in the ONPs, in 1984, ISA appeared for the first time. In addition to outbreaks of diseases, the enormous production growth in the late 1980s had led to salmon prices being halved between 1985 and 1989. As a reaction, the United States of

America accused Norway of dumping and imposed a punitive import duty on Norwegian salmon in 1991. This all led the industry into its first severe crisis and the farms started to go bankrupt (Norwegian Seafood Federation & Norwegian Seafood Council, 2011).

In consequence, the government began to liberalize the regulatory regime in 1992 and abandoned the regulation preventing farmers from owning more than one license as well as the requirements for local ownership. Thereupon, restructuring and controlled consolidation started to take place and larger firms were created "that soon started to grow internationally by purchasing companies in other countries" (Asche & Bjørndal, 2011, p. 35).

2.5.2 Focus on Market Stability & Sustainability from 1996 to 2019

In 1996, a feed quota regime was introduced in order to stabilize the industry growth and to prevent the European salmon markets from being oversupplied (FAO, 2005). Deeming this regime not sufficiently holistic, the government replaced the feed quota regime by the maximum allowed biomass (MAB) regime on 1st January 2005 (Nærings- og fiskeridepartementet, 2015). From then on, farmers were prohibited from having more living fish (measured in kg or tons) in their ONPs than what they were granted through their licensed MAB.

Further, the two-fold MAB regime marks the beginning of an increasing focus on sustainable circumstances of production: on the one hand, farmers were granted MAB limits on their licenses, on the other hand, production was also limited location-wise. Thereby, the regime did not only control overall production volumes but also provided for the consideration of fish health aspects and the environmental capacity of each location (FAO, 2005).

As of today, the MAB on licenses amounts to 780 tons for all administrative districts (fylker in Norwegian) except for Troms and Finnmark where the MAB amounts to 945 tons per licenses in order to account for the poorer growth conditions (i.e. lower sea-water temperatures) in these two northernmost regions.

From 2002 onwards, new licenses were no longer given out for free but had to be acquired by paying compensation to the government. From 2009, compensation also had to be paid for increased capacity on existing licenses. The allocation of the new licenses (or increased capacity on existing licenses) depended on varying criteria set by the changing political agendas of the government. In 2002, for example, female owners were prioritized. In 2009, it was farmers vertically integrating their production processes and adding fish processing to their operations (Nærings- og fiskeridepartementet, 2015). Since 2013, the allocation of licenses mainly depended on the environmental compatibility of increased production which usually was evaluated by governmental risk assessments and based on research by leading institutes such as the Institute of Marine Research in Bergen (Havforskningsinstituttet, 2018).

2.5.3 MAB Regime

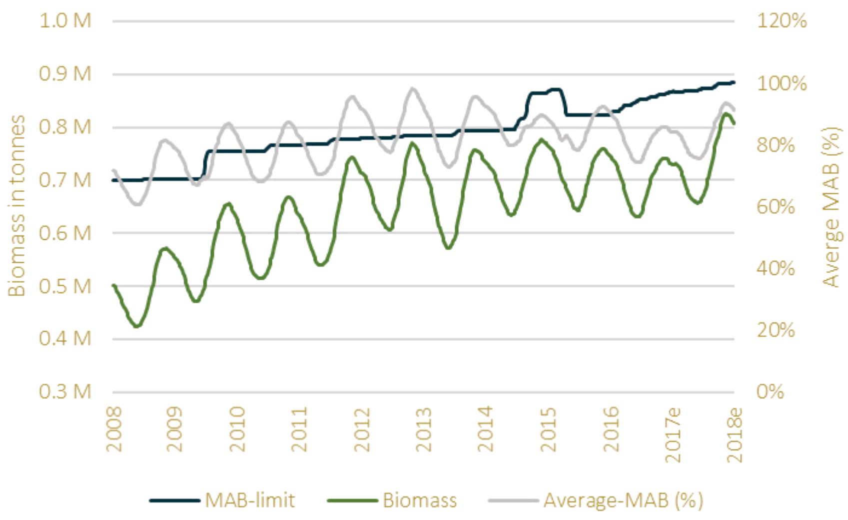
In order to better understand the operational changes brought by the Production Area Regulation, some aspects of the MAB regime require a more detailed analysis. In general, one license can be connected to more than one location. This allows the farmers to plan their production more flexibly and to manage locations lying fallow after the termination of a production cycle. Furthermore, the locality MAB is to be seen completely independent from the license MAB and may be equal to, higher or lower than the license MAB. In general, production locations' MABs are between 2,340 and 4,680 tons (Marine Harvest, 2018).

Companies that have vertically integrated the processing of substantial shares of their stock into their business operations can deploy their allocated MAB throughout several geographic regions. These MABs are also referred to as 'maximum inter-regional biomasses' (Pettersen Aubell & Haugen Hamarsland, 2018). This exemption provides the respective firms with additional flexibility and is justified with the argument to keep the economically important processing facilities in their respective localities and the country (Nærings- og fiskeridepartementet, 2004). This political measure is not without controversy as it provides larger firms with an unbalanced competitive advantage over smaller ones with fewer licenses. However, it is a key element of the government's endeavors to prevent fish processing from being offshored to China or other Asian or African low-wage countries (SINTEF, 2013).

Even though there exists a relative consensus on that economies of scale give larger companies additional economic advantages over small and medium-sized salmon grow-out farmers (Asche, et al., 2013), this does not necessarily apply to the utilization of production capacity. On the one hand, one could argue that flexibility in terms of capacity distribution gives larger businesses clear advantages. On the other hand, small and medium-sized companies might be advantaged due to less and more manageable process complexity. Either way, research on the dependency of MAB utilization on company size does not exist so far and might be an interesting area of research for future academic works.

The utilization of the MAB varies from company to company and is influenced by a variety of factors such as sea temperature, fish health, productivity, and other conditions. The average annual production per license currently amounts to 1,025 tons of whole fish equivalent (WFE) (Marine Harvest, 2018). As displayed in Figure 10, Marine Harvest (2018) detected a decreasing average utilization in MAB-capacity after 2015. PwC (2017) identified this circumstance in their analysis as a potential for future growth within existing licenses. Moreover, they also point out the fact that grow-out farmers until now do not make use of the opportunity to the exceed their licensed MAB-levels over a limited period while keeping the annual average biomass level within the limit. This opportunity provided by the Bremnes model would also provide companies with additional growth possibility within their existing production capacity.

Figure 10 – Estimated MAB Utilization in Norway, 2008 – 2018



Based on Marine Harvest, 2018

2.5.4 Development Licenses

On top of the ‘normal’ licenses that were introduced in the previous subsections, Norwegian authorities announced a new category of license in November 2015 – so-called development licenses. Those licenses are used to stir innovation in the industry and to develop solutions to its challenges such as, for example, salmon lice and discharge. In particular, they aim to speed up the research and development of the previously described CCSs and increase their competitiveness for them to become an economically viable alternative to the current ONPs

(PwC, 2017). Also, interest and the speed of innovation in offshore farming is hoped to be boosted by this type of subsidization.

With this end in view, the development licenses "are intended to motivate investment into new farming technologies and are allocated free of charge for up to 15 years. Subsequently, […] the licenses could be converted into commercial licenses at the cost of NOK 10 million", in case the project is carried out in line with the predetermined criteria (Marine Harvest, 2018, p. 74). The 105 concept applications of which 13 have been approved mainly vary in their exposure to the sea, which is open vs. closed structures and submerged vs. unsubmerged solutions (Marine Harvest, 2018).

Despite their positive intention, development licenses are also seen critically to a certain extent as the evaluation methods currently adopted prioritize projects with significant investments. Thereby, this governmental initiative is at risk to reward "the projects with the highest investment costs and the most innovative solution. This is opposed to rewarding the solutions that may help solve the challenges in a more cost-effective way" (PwC, 2017, p. 6).

With regard to total production volumes, the licenses are not expected to contribute significantly to the production growth in the short run. PwC (2017) industry experts estimate the short-term growth potential to be around 6 % (assuming an approval rate of 1/3 of all applications). In the long run, however, they are anticipated to contribute to increased long-term production capacity – albeit at a higher cost level than today's (PwC, 2017).

2.5.5 'Green' & 'Super-Green' Licenses

Preceding the production area regulation, the Norwegian government started to attach environmental conditions to the allocation of new salmon farming licenses in 2014 (Furuset, 2015). At this time, company profitability was excellent, market conditions seemed promising, and from a purely economic perspective, further volume expansions would have been the logical consequence. However, sea lice and escapes were beginning to pose substantial threats to the industry's environmental viability and the government was forced to consider any further allocations of additional licenses very carefully and balance economic and environmental interests against each other.

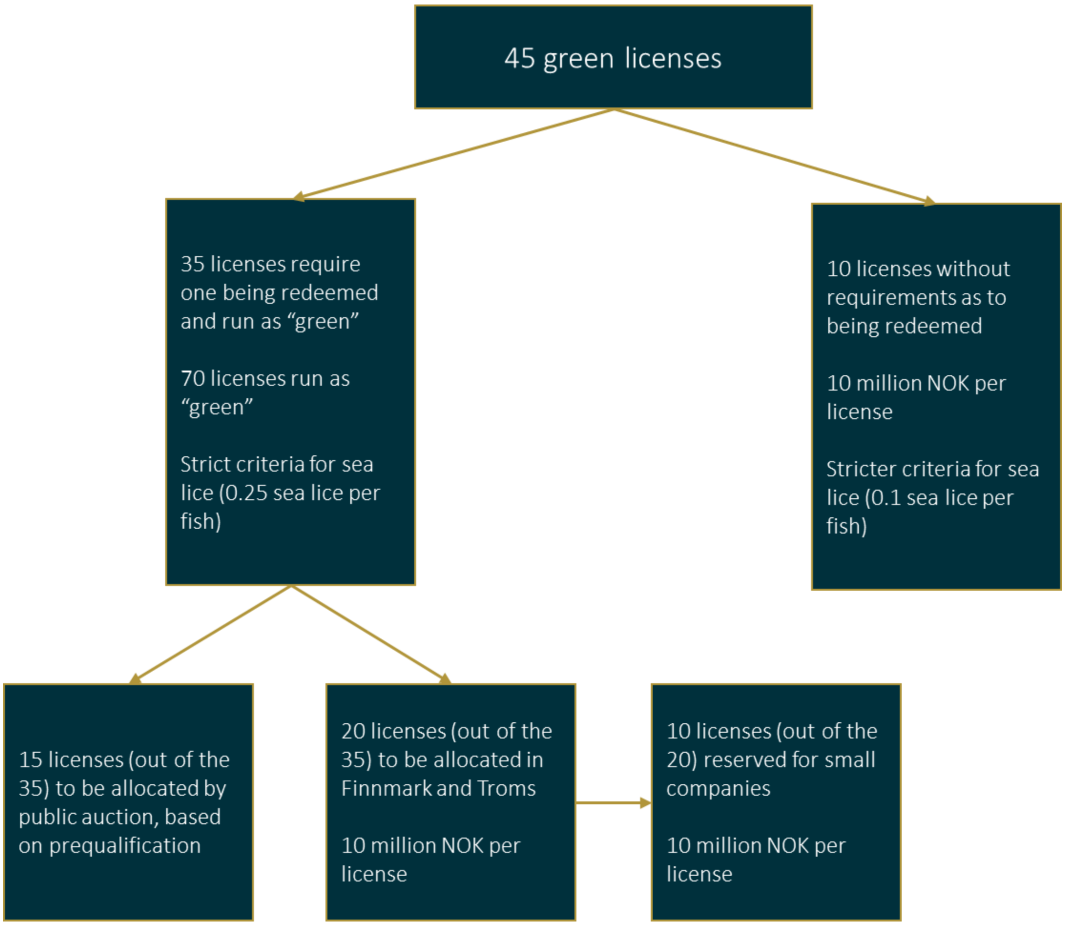
In consequence, the Ministry of Fisheries and Coastal Affairs came up with a new type of license that was allocated under much tighter conditions than the present ones. The current fixed critical limit of a maximum of 0.5 sea lice per fish should be significantly reduced and licenses should be allocated only to those able to come up with new solutions concerning sea lice and escapes (Hersoug, 2015).

In total, the Norwegian government established 45 new, so-called ‘green’ licenses that were subject to strict environmental criteria on sea lice, escape risk and other environmental factors (SeafoodSource, 2012). Since the ministry wished to also embed regional priorities, consider company size and use both public auction and allocation by fixed price, the allocation scheme turned out quite complicated and the licenses were dealt out to three superordinate groups.

10 ‘super-green’ licenses with stricter criteria for sea lice were awarded at a per-license price of 10 million NOK (under 1/5 the market price). 20 licenses were sold in the two northernmost counties, Troms and Finnmark, also at 10 million NOK per license and 15 licenses were awarded in a closed auction (Furuset, 2015). The latter two groups were also obliged to redeem an existing license for each newly awarded license in return for which the respective company was then awarded a second ‘green’ license. Therefore, this allocation scheme provided for 70 ‘green’ licenses (0.25 sea lice per fish) plus 10 ‘super-green’ licenses (0.1 sea lice per fish) (Hersoug, 2015). Figure 11 provides an overview of the allocation regime.

The selection criteria and the finally selected farms that were awarded licenses were a “topic of huge debate and acrimony in the sector” (Furuset, 2015). Specifically, the fact that the Norwegian fish farm company Norway Royal Salmon was awarded 1/3 of all assigned green licenses raised critical questions about the objectivity of the selection criteria in the competitive tendering procedure (OLET, 2015).

Figure 11 – Allocation of 'Green' & 'Super-Green' Licenses in 2014



Adapted from Hersoug, 2015

2.5.6 Production Area Regulation

In the course of Stoltenberg's Second Cabinet between 2005 and 2013, the Ministry of Fisheries and Coastal Affairs developed two strategies for a competitive and environmentally sustainable maritime industry (Fiskeri- og kystdepartementet, 2009; 2007). Against the backdrop of these strategies, a group of experts, the Area Committee (Arealutvalget in Norwegian), was instructed to come up with a superordinate area structure for the industry and they delivered their report 'Effective and sustainable area utilization in the maritime industry' in early 2011. In this report, the experts suggested to divide the Norwegian coast into different 'production areas' and to steer sustainability measures separately in the respective areas with fish mortality as the main indicator (Gullestad, et al., 2011). "While the idea of using production areas and put-out zones received wide acclaim, the use of fish mortality as the main indicator was met with stern resistance" (Hersoug, 2015). Therefore, the main indicator was changed to the frequency of sea lice when the idea was further developed (Fiskeri- og kystdepartementet, 2013).

In a hearing in 2014, the traffic light system was suggested for the first time as one out of three alternatives to manage continued industry growth and make it predictable to a more secure extent (Nærings- og fiskeridepartementet, 2014). On March 20th, 2015, the Norwegian Parliament (Stortinget) presented the main features of the traffic light system in their report Meld. St. 16 (2014-2015) 'Predictable and environmentally sustainable growth in Norwegian salmon- and trout-farming' (Nærings- og fiskeridepartementet, 2015). After some further political work on how to divide the Norwegian coast and adaptions of linked regulations, the Production Area Regulation came into effect on October 15th, 2017.

§ 1 states the regulation's primary purpose as follows: The regulation shall advance the aquaculture industry's profitability and competitiveness within the parameters set for an environmentally sustainable development and contribute to value creation along the coast by the set up of production areas and through the regulation of production capacity for salmon, trout and rainbow trout aquaculture (Nærings- og fiskeridepartementet, 2017a).

Next to the necessity to counteract the industry's two main threats, salmon lice and escape, the regulations second main intention was to reduce the ad-hoc character of political decision-making regarding industry growth (Nærings- og fiskeridepartementet, 2015). Up until the introduction of the Production Area Regulation, future industry growth and its regulation through the Norwegian authorities were always difficult to predict. By reducing political latitude, the new regulation should, therefore, provide industry players with a more stable and predictable framework for growth.

The Production Area Regulation's centerpiece is a traffic light system for whose enforcement the Norwegian coast was divided into 13 geographical areas of production. Based on the level of environmental threat, each area is marked either green (low risk/ influence), yellow (moderate risk/ influence) or red (high risk/ influence). As of today, the only indicator of environmental threat is the risk of mortality of wild salmon populations due to lice infestation. For future assessments, this indicator might, however, be adapted or augmented by additional environmental factors (PwC, 2017).

The mortality is estimated by the Norwegian Institute of Marine Research and published and provided to the Ministry of Trade, Industry and Fisheries in a yearly risk report since 2011 already (Havforskningsinstituttet, 2019). The institute estimates the mortality based on real-life observations (e.g. sea temperatures and lice counts from fish farms) but also models, e.g. for migration patterns of wild stocks, probability of death, infestation pressure, etc. (Havforskningsinstituttet, 2018). Given the institute's physical-biological model, their assessment is decisive for if the MABs can be increased, stay the same or have to be decreased.

For an overview, the critical limits and effects resulting from the Production Area Regulation are summarized in Table 2.

Table 2 – Critical Limits & Effects of the Production Area Regulation

	Low risk/ influence	Moderate risk/ influence	High risk/ influence
Criteria	It is probable that < 10 % of the population dies due to lice infection	It is probable that 10 – 30 % of the population dies due to lice infection	It is probable that > 30 % of the population dies due to lice infection
Effect of the regulation	2 % growth on existing MAB 4 % growth offered through auction	No change in MAB	6 % reduction in MAB

Based on Norwegian Ministry of Trade, Industry and Fisheries, 2015

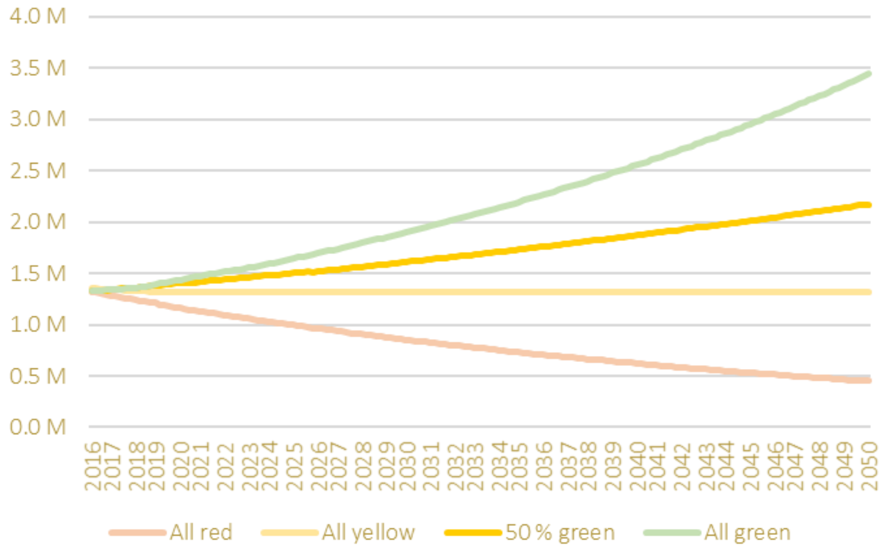
The salmon grow-out farmers, represented by Sjømat Norge, complained about the model and argued that it would not be sufficiently sophisticated to decide on the entire Norwegian aquaculture industry's growth. Additionally, they blamed the Ministry of Trade, Industry and Fisheries for basing their decision upon positively false lice counts. In consequence, they suggested an alternative model on their initiative, which was, however, rejected (Nærings- og fiskeridepartementet, 2016).

Based on monitoring data from 2016 and 2017, the government announced the condition for growth on existing licenses at the end of 2017. 8 of 13 areas were defined as 'green' and can, therefore, grow by 6 % every second year. All companies were offered a 2 % growth on existing licenses, in addition to a maximum 6 % growth for sites complying with very rigorous environmental standards. 2 of the 13 areas were defined as 'red' in 2017 such that grow-out farmers in those areas would have to decrease their production levels according to the traffic light system.

However, reduction in production capacity was predicted not to be imposed before 2019 (Marine Harvest, 2018) and has not been imposed as of today due to a dubious legislative basis (Schmidt, 2019). In January, an imposition of biomass reduction for the 'red' areas was expected for this year and the industry is expectantly awaiting further developments (Thomsen, 2019). Yet, as the year is approaching its third quarter now, the industry experts from the Norwegian Institute of Marine Research are not expecting imposed biomass reductions before 2020 (Rogne, et al., 2019). Since the environmental status of the areas is supposed to be updated every second year (which would soon be the case), salmon grow-out farmers in the two 'red' areas still hope to be able to improve on the environmental situation and thereby avoid biomass reduction impositions (Nærings- og fiskeridepartementet, 2015).

The magnitude of the impact of the production areas' assessment and categorization as either 'green', 'yellow' or 'red' is illustrated by means of four small case scenarios in an analysis by PwC (2017). In their estimate, displayed in Figure 12, PwC (2017) simulated four different scenarios and calculated the development of the total national harvest volume until 2050. Here, the scenario 'All green' sets the upper limit for the maximum growth the system would allow given its current setup. This scenario, just like the worst case 'All red' scenario, functions as a benchmark for more realistic cases. According to PwC (2017), the '50 % green' scenario with a growth of 0.85 million tons on existing licenses from 2017 to 2050 can be deemed the most realistic and meaningful case.

Figure 12 – Traffic Light Growth Potential until 2050



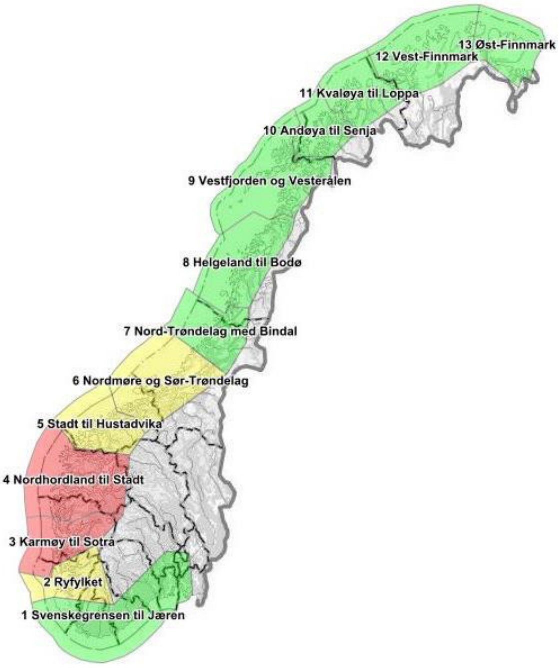
Adapted from PwC, 2017

Based on geography and ocean currents, the coast was divided into the 13 areas which were labeled and classified as follows:

Area No.	Area name	Area status
Area 1	Svenskegrensen til Jæren	green
Area 2	Ryfylke	yellow
Area 3	Karmøy til Sotra	red
Area 4	Nordhordland til Stadt	red
Area 5	Stadt til Hustadvika	yellow
Area 6	Nordmøre og Sør-Trøndelag	yellow
Area 7	Nord-Trøndelag med Bindal	green
Area 8	Helgeland til Bodø	green
Area 9	Vestfjorden og Vesterålen	green
Area 10	Andøya til Senja	green
Area 11	Kvaløya til Loppa	green
Area 12	Vest-Finnmark	green
Area 13	Øst-Finnmark	green

Figure 13 also displays the areas and their given status per May 2019 geographically.

Figure 13 – Production Areas and their Status from May 2019



Adapted from Fiskeridirektoratet, 2019b

Discussing the Production Area Regulation, it should be noted that the changes in MAB apply to license MAB only, locality MAB is not affected. If companies are restricted by locality MAB in any way, they are still forced to apply separately for increased locality MAB, just like SalMar Farming recently did for a location in production area 10 (Andøya til Senja) (SalMar Farming, 2018). However, literature does not reveal any larger conflicts between locality MAB and license MAB. Since the Production Area Regulation only regulates the license MAB, locality MAB is not further discussed in this context.

Summing up the history of the Norwegian salmon aquaculture regulation, there has been a shift of focus from maintaining local ownership and employment to ensuring an environmentally and economically sustainable industry. In this regard, the MAB regime was introduced in 2005 as a control measure for production volumes. Towards the end of 2017, the Production Area Regulation was introduced as a measure to ty future production growth to a chosen environmental indicator for two reasons. First, the two most serious environmental threats, salmon lice and escapes have to be overcome for a successful future of the industry. Second, industry growth should become more stable and predictable. For this purpose, the coastline was divided into 13 production areas, which were marked according to a traffic light system depending on their environmental status. 'Red' areas will be imposed biomass reductions, 'yellow' areas do not experience any change in MAB whereas 'green' areas will get the opportunity to grow at two-year intervals. Figure 14 provides a visual summary of the previous subsections. Since the license auctions from 2018 are the centerpiece of the paradox detected by Pettersen Aubell & Haugen Hamarsland (2018) and primary subject of the analyses of this thesis, the auctioning process will be introduced in the following and close this regulatory section.

Figure 14 – Historical Development of Government Initiatives, 1960 – 2019

Adapted from PwC, 2017

2.5.7 Fixed-Price & Auctioned Licenses 2018

Subsequent to the introduction of the Production Area Regulation at the end of 2017, the government began to offer additional production capacity to the companies in 2018 for the first time under the traffic light system.

Apportioning new salmon production licenses, the Norwegian Ministry of Trade, Industry and Fisheries first offered existing grow-out farms in the 'green' production areas (1, 7 – 13) to apply for the granted 2 % growth at a fixed price of 120,000 NOK per ton until the January 31st, 2018 (Fiskeridirektoratet, 2018b; Nærings- og fiskeridepartementet, 2017b). In total, 47 companies applied and were granted a production growth of 7,897 tons distributed on 449 out of 461 available licenses (corresponding to more than 97 %). Given the fixed price of 120,000 NOK per ton, the sale generated a total income of almost 950 million NOK (947,640,000) for the country's communities (Nærings- og fiskeridepartementet, 2018a). A list with the application details of all companies that were allocated additional production capacity can be found in Appendix A.

Subsequent to this fixed-price sale, the government decided to allocate additional licenses through an auction respectively several auctions in the further course of the year. Technically and strategically, the auction arrangement was kept relatively simple such that participants with fewer resources could also properly prepare for the auction(s) and were not disproportionately disadvantaged (SalmonBusiness, 2018b). After a trial auction on June 14th, the first 97 % (14,945) of the totally available 15,359 tons of additional production capacity were auctioned over three days between June 18th and June 20th to 14 different companies. Sold at a weighted average of 195,071 NOK per ton, the auctioned licenses generated total revenue of 2.9 billion NOK (2,915,343,000) (Nærings- og fiskeridepartementet, 2018b). The financial details of this auction can be found in Appendix B. Of the remaining 414 tons, 363 tons could be auctioned off in a closing licensing round on September 17th so that 99.7 % of the total available growth capacity could be sold in 2018. Sold at a weighted average of 196,582 NOK per ton, the auctioned licenses generated another 81 million NOK (81,385,035) (Nærings- og fiskeridepartementet, 2018c). The financial details of this auction can be found in Appendix C.

After this round, the Ministry of Trade, Industry and Fisheries decided to not hold any further auctions in this licensing round. The last 51 tons of capacity remained therefore unauctioned.

Summarizing both auctions from June and September 2018, they generated total revenue of almost 3 billion NOK (2,996,728,035). Adding the 947.64 million NOK from the fixed-price sales in January, the total income through selling additional and new salmon production licenses accounts for almost 4 billion NOK (3,944,368,035). Table 3 summarizes the financial key data of the first capacity growth since 2012 and under the traffic light system (Solås, 2017).

Table 3 – Summary of the 2018 Production License Sale

	Companies	Tons	Price per ton	Total Revenue
Fixed-Price Sale January 2018	47	7,897	120,000 NOK	947,640,000 NOK
Auction June 2018	14	14,945	195,071 NOK*	2,915,343,000 NOK
Auction September 2018	4	414	196,582 NOK*	81,385,035 NOK
SUM		**23,256**		**3,944,368,035 NOK**

*Weighted average

Based on Fiskeridirektoratet, 2018d; Fiskeridirektoratet, 2018e; Fiskeridirektoratet, 2018f

2.6 Bioeconomic Modeling in Aquaculture

In the section before last, the production process' eight economically most relevant decision variables were identified from academic industry literature. Moreover, the previous section introduced the regulatory aspect of salmon grow-out farming as another variable to be taken into consideration. Synthesizing both sections, the variables are of economic, biological, technical, physical, environmental as well as institutional nature and partially interrelate with each other. This gives a high degree of complexity to the grow-out farmers' endeavor to optimize the economic performance of their businesses.

To support the economic decision making and effort to ascertain the best utilization of the biological resource, Atlantic salmon, bioeconomic modeling arose from the industry's beginning (Allen, et al., 1984). The following subsection will provide a short overview of the different bioeconomic models that have been developed since then. However, as Pettersen Aubell & Haugen Hamarsland (2018) built their research upon the bioeconomic model presented by Asche & Bjørndal (2011), focus will be laid on the optimal rotation problem as proposed by Asche & Bjørndal (2011). Concluding the secondary research part of this thesis, an overview of the model set up by Pettersen Aubell & Haugen Hamarsland (2018) will be given in the following section before this chapter will be concluded by an encompassing summary.

2.6.1 Literature Overview

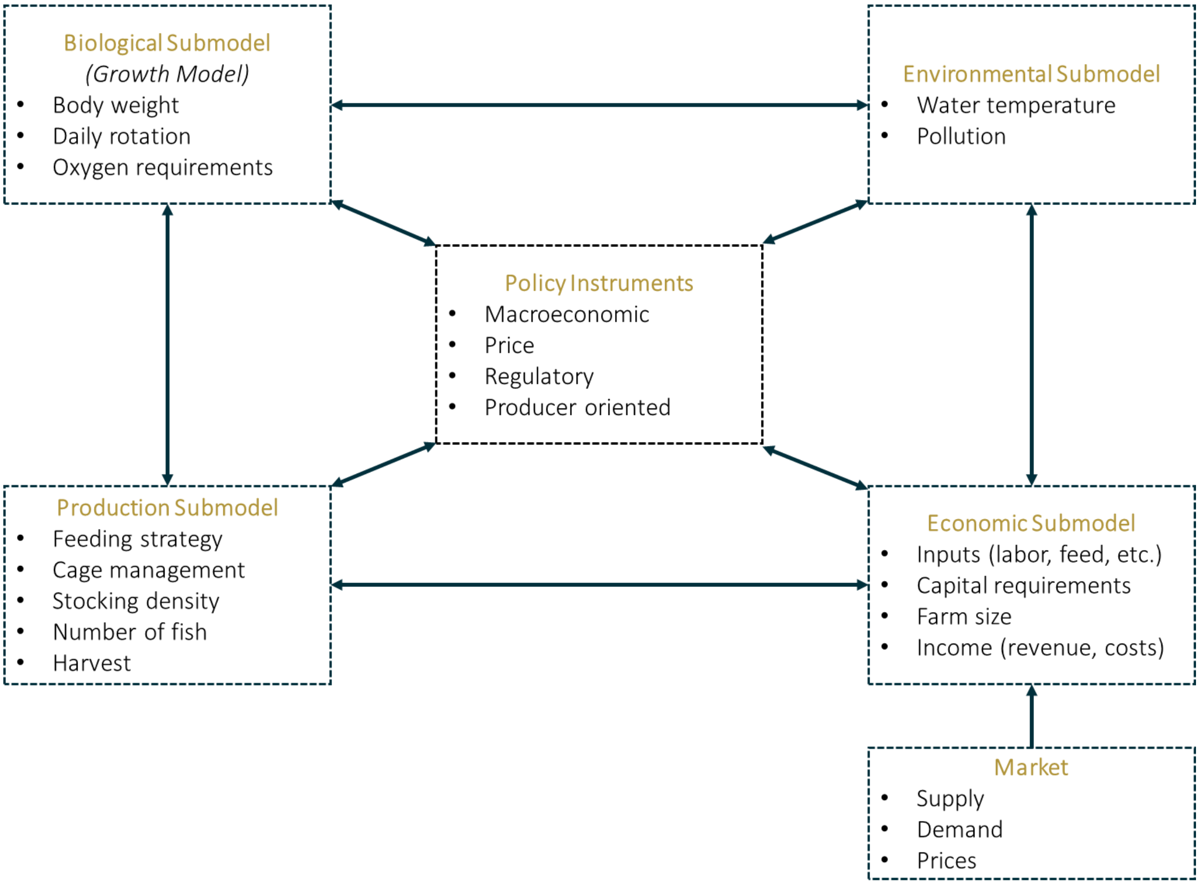
In the last 45 years, academia came up with a vast amount of bioeconomic models for aquaculture. To keep track of all scientific progress made during the years, different overviews of the scientific production related to bioeconomic modeling in aquaculture have been created about once per decade.

Allen, et al. started in 1984 by summarizing bioeconomic modeling in aquaculture for the timeframe 1974 – 1983. Next, Leung (1994) analyzed 32 studies conducted between 1984 – 1993 and Pomeroy, et al. (2008) identified seven papers during the period of 1994 – 2003. Most recently, Llorente & Luna (2016) gave an overview of bioeconomic models in aquaculture during the period 2004 – 2015. The cited reviews cover studies with various degrees of sophistication and related to all kinds of fish species, locations, and productions systems.

Whereas analyzing them in depth would exceed the scope of this thesis, Figure 15 provides an overview of how the models can be broken down into the different aspects of the production process. Looking at the separate submodels and the listed policy instruments in Figure 15, it becomes apparent that they cover the majority of the factors that have been covered in the previous two sections. Therefore, it can be assumed that academic literature has not systematically overlooked any considerable factors influencing the profitability of salmon aquaculture.

Even though Pomeroy, et al. (2008) critically comment that bioeconomic models for aquacultural systems would still be relatively limited compared to equivalent models for agricultural systems, they are historically based on the academically omnipresent formula by Martin Faustmann. In the 1840s and 1850s, Faustmann, a German forester, developed a formula to calculate the value of trees on a stand level and to support harvesting decisions in forestry. Technically, he solved the rotation problem for maximizing the present value of the income stream for forest rotation. Given a certain capacity of land, he argued that a tree population should be cut when its marginal increase in value is equal to the opportunity cost of investment in trees and land (1854; 1849). Given the similarities of forestry and aquaculture in decisive industry characteristics (i.e. limited availability of space and rotation of the resource), the formula was applied to aquaculture throughout the history of bioeconomic modeling in aquaculture.

Figure 15 – Diagrammatic Representation of a general Bioeconomic Model



Adapted from Pomeroy, et al., 2008

In the following subsection, the bioeconomic model for determining the optimal harvesting time of farmed salmon by Frank Asche and Trond Bjørndal (2011) will be presented for the following two reasons. First, both authors enjoy a high reputation as two of the world's leading experts with a high level of industry knowledge and experience (Grafton, 2010). Second, Pettersen Aubell & Haugen Hamarsland (2018) also built their model upon the work by Asche & Bjørndal (2011). Therefore, a thorough analysis of their work is only possible with a general understanding of the underlying optimal rotation problem.

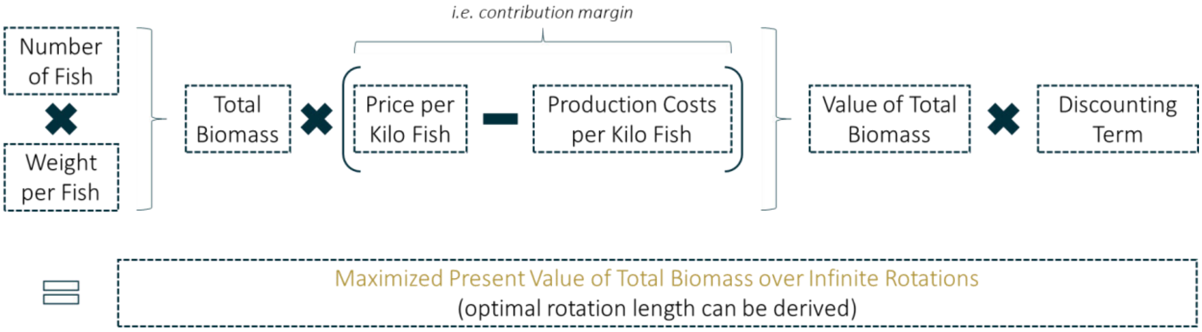
2.6.2 The Optimal Rotation Problem

In the appendix of chapter 9 'Optimal Harvesting of Farmed Fish' of their work 'The Economics of Salmon Aquaculture', Asche & Bjørndal (2011) introduced in detail a bioeconomic model for the best possible approximation of the optimal harvesting time for farmed salmon. The model contains a number of input parameters which will be shortly introduced in the following:

- Number of Fish $\boldsymbol{N(t)}$
- Weight per Fish $\boldsymbol{w(t)}$
- Total Biomass $\boldsymbol{B(t)}$
- Price per Kilo Fish $\boldsymbol{p(w(t))}$
- Production Costs per Kilo Fish $\boldsymbol{C}$
- Value of Total Biomass $\boldsymbol{V(t)}$
- Discount Factor $\boldsymbol{\frac{1}{e^{rt}-1}}$
- Optimal Rotation Length $\boldsymbol{t}$

The parameters' relations are illustrated in Figure 16 for a better understanding and quicker overview.

Figure 16 – Calculatory Components of the Optimal Rotation Problem



Based on Asche & Bjørndal, 2011

Beginning with the number of fish at time t $N(t)$, the model assumes a given number of recruits released into a pen that is reduced over time by the mortality rate. The weight per fish at time t is denoted $w(t)$ where the time rate of change in weight is given by a growth function. In Asche & Bjørndal's (2011) model, this function encompasses the three variables weight, number of fish (density) and feed quantity. However, this growth model could theoretically also take further or different variables, such as salinity or light into consideration. The composition of the growth model will be taken up again at a later point of this thesis.

Multiplying both terms (number of fish and weight per fish) will then yield the total biomass $B(t)$. Even if the fish in the ONP grow at different rates in reality, the model assumes all of them to have the same weight for simplicity. The total biomass $B(t)$ increases as long as the relative growth rate of the fish exceeds the mortality rate and reaches its maximum when the relative growth rate equals the mortality rate. This will happen before the fish reach their maximum weight as the mortality rate will cancel out individual growth at an earlier point in time.

Multiplying the total biomass $B(t)$ with the contribution margin of the fish (price per kilo fish $p(w(t))$ minus production costs per kilo fish C) will then yield the value of total biomass $V(t)$. Regarding the price per kilo fish $p(w(t))$, it should be noted that the price cycles described in Subsection 2.3.2 must be considered and that the price is, therefore, dependent on the month of the year as well as on the weight of the fish. With respect to the costs, the model assumes only variable costs to be relevant for the decision of the optimal harvesting time. Here, feed and processing (harvesting) costs make up the largest share of the total costs as also previously described in the Subsections 2.4.3 (Feeding) and 2.4.8 (Harvesting & Slaughtering). Table 4 illustrates the cost structure of farmed salmon production also in detail.

Table 4 – Cost Structure of Atlantic Salmon Production

	Norway (EUR)
Feed	1.70 €
Primary processing	0.33 €
Smolt	0.35 €
Salary	0.24 €
Maintenance	0.16 €
Well boat	0.15 €
Depreciation	0.13 €
Mortality	0.06 €
Admin cost	0.12 €
Other	0.72 €
Total	**3.96 €**

Adapted from Marine Harvest, 2018

Since harvesting can give space to another year class of recruits and space is limited due to licensing, it is not sufficient to only consider one single harvest but also future rotations (and their potential revenue) need to be included into this maximization problem. In order to find the optimal rotation length t that maximizes the present value of total biomass over infinite rotations, the value of total biomass $V(t)$ is multiplied by a discount factor $\frac{1}{e^{rt}-1}$. Maximizing the present value of total biomass over infinite rotations, $\pi(t) = \frac{V(t)}{e^{rt}-1}$, finally yields the optimal rotation length t. It is given when the marginal revenue is equal to the marginal costs of keeping the fish in the ONP (i.e. opportunity costs plus production costs).

2.7 Pettersen Aubell & Haugen Hamarsland's Work

Since the paradox raised by the net effect analysis by Pettersen Aubell & Haugen Hamarsland (2018) is the centerpiece of the research question of this thesis, a short introduction into their work and relevant findings will be given in the following three subsections. Building upon the bioeconomic model by Asche & Bjørndal (2011), they first introduced two model extensions – capacity constraints and fallowing. Then, they developed their own growth and price models and finally analyzed the net effect per license of the Production Area Regulation based on the current color of each area.

2.7.1 Model Extensions – Capacity Constraints & Fallowing

Initially, Pettersen Aubell & Haugen Hamarsland (2018) detected that no other author previously had addressed the issue that salmon grow-out farmers might not be able to stick to the optimal rotation length due to capacity constraints. With a binding capacity constraint $B(t) < MAB$, farmers might have to harvest earlier than what would be theoretically optimal. This could have a two-fold effect on the farmers' revenues: first, the pure volume would be decreased and second, a lower price per kilo would be the result (further assuming that fish with a higher weight are also sold at higher market prices per kilo). In the context of capacity and possibly constraint capacity, Pettersen Aubell & Haugen Hamarsland (2018) also define a farmer's WTP for change in capacity θ as the change in profits divided by the change in capacity with the unit NOK per kilo. Additionally, they introduced a fallowing period of 2 months duration for each production cycle which slightly changes the abovementioned profit function to $\pi(t) = \frac{V(t)}{e^{r(t+2)}-1}$.

2.7.2 Growth Model

In order to be able to estimate the farmers' WTP for change in capacity, Pettersen Aubell & Haugen Hamarsland (2018) created a growth model for the weight of an individual fish using a third-degree polynomial functional form:

Equation 1 – Growth Function

$$w_{it} = \beta_1 time^2 + \beta_2 time^3 + \beta_3 time^2 \times prod\_area + \beta_4 time^3 \times prod\_area + \beta_5 lice_{it} + \beta_6 density_{it} + \delta month + \lambda_t + \alpha_i + \varepsilon_{it}$$

Pettersen Aubell & Haugen Hamarsland, 2018

The interaction terms between the second- and the third-degree component of the time variable and the production area were included to obtain separate growth coefficients for each production area and to partial out fixed effects between locations. $lice_{it}$, i.e. the average number of lice per fish for a given location i in a given month t, and $density_{it}$, i.e. the average number of fish per ONP for a given location i in a given month t, have been included as control variables. Especially controlling for the month is important in order to partial out any common macro effects that change over time. The parameters λ_t, α_i, ε_{it} are error components.

Assessing further potential explanatory variables, Pettersen Aubell & Haugen Hamarsland (2018) decided to not include factors like daylight, salinity, density or diseases even though they have an impact on the growth rate of the fish as presented earlier.

For density, there was only an auxiliary variable available, i.e. the average number of fish per ONP for a given location i in a given month t. Due to uncertainty concerning to if this variable explains the real effect of density on the fish' growth rate, Pettersen Aubell & Haugen Hamarsland (2018) decided to include the variable only to control for the variation related to the amount of fish per pen, but to exclude it from any weight estimations.

Regarding lice, plotting this variable against the weight per fish revealed a positive relationship which contradicts any presented research of lice preventing salmon growth. Therefore, $lice_{it}$ was also included as a control variable only. After plotting temperature against weight per fish, this variable was not included either due to ambiguity in the relationship. The data for the two main diseases PD and ISA contained a lot of missing values, which is why both variables were also excluded from the model.

In terms of feed usage, they were unable to find a suitable instrument since feed usage most likely explains fish weight and growth, but fish weight and growth most likely also explain feed usage. As Pettersen Aubell & Haugen Hamarsland (2018) were not able to circumvent this simultaneity problem, they also excluded this variable from the regression model.

Concerning other environmental conditions such as daylight or salinity, they were confident to have controlled for any month- or location-fixed effects as previously described and therefore allowed for this model simplification. After having validated their growth model, Pettersen Aubell & Haugen Hamarsland (2018) decided to include month-, year- and location-fixed effects.

2.7.3 Price Model

As the estimation of the farmers' WTP for change in capacity also requires an assumption of the price of salmon, Pettersen Aubell & Haugen Hamarsland (2018) also decided to set up an empirical price function based on historical, inflation-adjusted price data from the NQSALMON. Deeming a quadratic function suitable, they set up the following price function:

Equation 2 – Price Function

$$p(w) = \beta_1 + \beta_2 w + \beta_3 w^2 + \delta month + \lambda year + \varepsilon$$

Pettersen Aubell & Haugen Hamarsland, 2018

By including month as an explanatory variable, Pettersen Aubell & Haugen Hamarsland (2018) accounted for the fact that relative prices between different weight classes follow different month-dependent price patterns, as introduced in Subsection 2.3.2 – Price Cycles. Time-fixed effects were controlled for by including the parameter year. ε, again, functioned as an error term.

2.7.4 Net Effect Analysis

Having set up their growth and price function, Pettersen Aubell & Haugen Hamarsland (2018) finally could set up their model in order to complete their net effect analysis. They derived a growth function for each production area as well as a price function valid for all production areas.

They assumed a constant mortality rate and averaged the number of recruits per license per production area. Further, they assumed an interest rate of 6 % to reflect the opportunity costs in the Norwegian market (Kinserdal, 2017; PwC, 2016) and a production cost per kilo of 22 NOK as this was the average production cost from 2008 until 2016, excluding harvesting and slaughtering costs (Fiskeridirektoratet, 2018c). A summary of the initial setup parameters is shown in Table 5.

Table 5 – Initial Model Setup

Growth function	Derived from the data set for each production area
Price function	Derived from the data set
Mortality	Average mortality rate per production area
Recruits	Average number of recruits per license per production area
Interest rate	6 % p.a.
MAB	780 tons in production area 1 to 9
	945 tons in production area 10 to 13
Capacity increase	2 %
Capacity decrease	6 %
Production costs	22 NOK/kg

Adapted from Pettersen Aubell & Haugen Hamarsland, 2018

Having set up some the model, Pettersen Aubell & Haugen Hamarsland (2018) started their analysis by calculating the optimal rotation length, weight per fish at the time of harvesting and total profits over infinite rotations with the given parameters for two basic scenarios: first without capacity constraints, then with the current MAB constraints (780 respectively 945 tons). Subsequent to this, they introduced a 2 % increase in MAB and calculated the WTP for change in capacity, assuming that all production areas were classified green. Next, they compared these results to a scenario including a two-months fallowing period, which revealed a reduced WTP for the latter, as restricted use of the production license reduces the present value of future biomass.

Finally, they also evaluated the current status in order to be able to evaluate the net effect per license of the Production Area Regulation. The net effect for the green areas represents the economic gain of increasing production capacity by 2 % minus the cost of additional capacity of 120 NOK/kg. The net effect for the red areas is the economic loss of an imposed capacity reduction of 6 %, whereas the net effect for the yellow areas equals zero as capacity remains the same. The result of their analysis can be seen in Table 6 below.

As the calculations assumed capacity reductions for all ‘red’ areas, they incur a negative change in profits. The opposite applies to all ‘green’ areas as they can increase their production (the calculation is based on the model without fallowing and hence full capacity utilization). Looking at the net effect, however, it is of special interest here that an investment into additional production capacity is only profitable in the production areas 1, 8 and 9 (since their WTP for capacity lies above 120 NOK/kg). Since the capacity constraint is not binding in the areas 7, 12 and 13, the WTP in these 3 areas is equal to 0. Therefore, the net effect of buying growth in these areas is the negative value of the price that has to be paid for capacity increase in the respective area.

Table 6 – Total Effect of the Production Area Regulation

Area	WTP	Change in profits	Net effect
1	146.32	2,282,536	410,536
2	147.90	0	0
3	116.41	-5,448,147	-5,448,147
4	132.78	-6,214,179	-6,214,179
5	153.58	0	0
6	114.02	0	0
7	0.00	0	-1,872,000
8	136.02	2,121,986	249,986
9	129.06	2,013,317	141,317
10	113.86	2,151,970	-116,030
11	98.40	1,859,741	-408,259
12	0.00	0	-2,268,000
13	0.00	0	-2,268,000

Adapted from Pettersen Aubell & Haugen Hamarsland, 2018

In the areas 10 and 11, the WTP lies below 120 NOK/kg which leads to a negative net effect even though the change in profits is positive (see Table 6). Nevertheless, the demand for new production capacity has been extremely high both in the fixed-price sale in January 2018 as well as in the auctions in June and September 2018 which is summarized again in Table 7 below.

This gives rise to the question of what makes Norwegian salmon grow-out farmers buy increased production capacity even though bioeconomic analysis suggests this to be unprofitable. For this purpose, the following primary research part of this thesis will critically investigate the underlying assumptions of the analysis by Pettersen Aubell & Haugen Hamarsland (2018) and try to obtain further insights into the motivation behind the buying-decision that have not been detected, yet.

Table 7 – The Investment Behavior Paradox

Area	WTP according to Pettersen Aubell & Haugen Hamarsland (2018)	Weighted Average Price per kg		
		Fixed-Price Sale January 2018	Auction June 2018	Auction September 2018
1	146.32	120.00	132.00	132.50
2	147.90	-	-	-
3	116.41	-	-	-
4	132.78	-	-	-
5	153.58	-	-	-
6	114.02	-	-	-
7	0.00	120.00	215.17	206.00
8	136.02	120.00	250.77	245.69
9	129.06	120.00	231.82	-
10	113.86	120.00	164.50	-
11	98.40	120.00	162.98	129.00
12	0.00	120.00	165.89	-
13	0.00	102.00	153.49	-

Based on Fiskeridirektoratet, 2018d; Fiskeridirektoratet, 2018e; Fiskeridirektoratet, 2018f, Pettersen Aubell & Haugen Hamarsland, 2018

2.8 Summary of the Literature Review

Concluding, the following objectives were achieved:

1. To critically review and extensively examine industry literature on salmon market mechanisms and the production process with a special focus on the decision variables of salmon grow-out farmers *[Secondary Research]*
2. To critically review and extensively examine industry literature on the regulation of the Norwegian salmon aquaculture with a special focus on the role of production licenses, the 'Product Area Regulation' and the 2018 production license sale *[Secondary Research]*

The literature review provides the foundation for the following primary data collection, and several key aspects can be summarized. After having developed a deeper understanding of the Norwegian salmon aquaculture industry in regard to terminology, its historical background as well as economic development and size, a closer look was taken at the biological and technological foundations.

Even though the release of out-of-season smolts was meanwhile made possible by biotechnological progress, the release of salmon to sea pens is particularly dependent on their hatching in January. Typically, salmon are released either in next year's May (after sixteen months) or in September of the same year (after eight months) and not raised for longer than two years as their sexual maturation (and natural mortality) sets an upper limit to letting them grow and gain in weight. Even though closed containment systems and offshore aquaculture are on the rise as future technologies, open net-pens in coastal areas remain the predominant technology until now as the other two technologies still suffer from some severe technical but mainly profitability issues.

The previously mentioned release cycles in combination with a comparatively high slaughter age of the fish entail production and price cycles. In terms of production volumes, the industry is characterized by alternating over- and underproduction in cycles of 2 – 3 years. Investigating price cycles, the per kilo price for salmon is dependent on the weight class but also on the calendar week, which leads to varying price differences throughout the year in yearly recurring patterns.

In order to get an overview of how salmon grow-out farmers try to maximize their fish's growth, the production process was analyzed next with regard to the farmers' most important decision variables. The decision variables were analyzed considering their occurrence in the salmon life cycle.

Smolt quality refers to enhanced growth performance of the fish and reduced mortality and diverse traits are tried to optimize in breeding programs. Here, it must be noted that there exists a trade-off between the number of traits and the response to each trait.

Regarding smolt release, the industry aims to further delay the transfer of the fish in order to decrease the production time in the sea and reduce the sea lice issue. Further, older fish exhibit improved robustness, which is why decreased mortality is also hoped to be achieved through the transfer-delay. However, these endeavors require further improvement of the closed containment systems so that the development in this part of the production process remains a subject of speculation.

Feed is a topic of debate in particular regarding environmental sustainability for which the FIFO ratio serves as a main indicator. Economically, feed is the key cost driver and makes up about 50 % of the total production costs. Since the salmonid feed industry is, however, highly consolidated, competitive cost and growth advantages through individualized feed could not be detected in the literature. On the other hand, the feeding regime can be utilized to improve on fish growth even though this potential source for a competitive advantage uses to be company-confidential and is not widely covered in academic literature, either.

The environmental conditions temperature, oxygen, salinity, and light are highly biological and scientific in nature and their partial interaction adds further complexity.

According to most recent analyses, 13 °C is the temperature with the highest efficiency. Generally, south Norwegian regions exhibit a temperature advantage over north Norwegian regions even though global warming might change this in the long run.

The level of oxygen depends on various factors, amongst others also on sea-water temperature. Since the levels of oxygen required for the high densities of fish raised in the open net-pens cannot be met by natural sources such as fresh-water runoff or tidal movements, aeration and oxygenation systems compensate for this shortcoming.

As sea-water temperature, salinity can only be influenced indirectly through the choice of location, too. In general, higher salinity was shown to negatively influence the osmotic balance of the fish, in particular for out-of-season smolts. Therefore, brackish waters, e.g. in fjord sites might be preferred over full strength sea water by salmon grow-out farmers for increased flexibility in the release of the fish.

Since daylight varies a lot along the Norwegian coast and across seasons in the during the year, the fish are exposed to continuous light in order to speed up growth and defer sexual maturation.

Next, stocking density, i.e. the weight of fish kept in a given volume of water, was investigated. By law, stocking density is limited to up to 200,000 individual fish per unit and 25 kg fish per m^3. Nevertheless, salmon grow-out farmers rarely exceed densities of 20 kg fish per m^3 as increasing density is considered to decrease fish growth and increase mortality substantially. Looking at future land-based technologies, stocking density appears to be the key bottleneck as the profitability of the new technologies still require densities of up to 80 kg fish per m^3.

Salmon lice continue to be the economically most relevant challenge of the industry. Recently, the development of chemical resistance forced the industry into a change to thermal and mechanical measures. These, however, increased the post-treatment mortality of the fish considerably. Therefore, lumpfish who feed on salmon lice are hoped to be the new panacea against sea lice infestation. Yet, there does not exist an aquaculture for this species which would be needed to cover worldwide demand.

Loss of fish due to mortality is substantial and the country-wide average currently lies at around 20 %. Research on cause-specific mortality is, however, rare. This makes it even more difficult to explain the huge differences between production areas and farms where mortality ranges from 3.5 % to 43 %. Loss of fish due to escape receives wide media attention and also states a severe environmental problem which is, however, neglectable from a purely economic perspective.

Finally, harvesting and slaughtering have seen some significant improvements with regard to animal welfare and are aimed to be completely automized in future. Economically more important remains, however, the decision of when to market the fish. Price forecasts take a central role in this regard. Meanwhile, salmon grow-out farmers are enabled to reduce the financial risk at least to a certain extent by hedging their production volumes on the Fish Pool commodity exchange.

Following thesis objective 2, the regulation of the Norwegian salmon aquaculture was critically reviewed and examined. In the industry's first quarter-century, the focus of governmental regulations was on local ownership and employment and farmers are allocated only one license each.

Upon an extreme industry growth in this period and a liberalization of the regulation regime from 1992, feed quotas are introduced in 1996 and replaced by the MAB regime in 2005. Currently, the MAB amounts to 780 tons per license for all administrative districts except for Troms and Finnmark (945 tons).

Recently, the government also began to foster industry innovation and sustainability by giving out development licenses (based on project innovation and investment costs) and 'green' and 'super-green' licenses (subject to environmental constraints).

The Production Area Regulation came into effect in October 2017 and regulates industry growth in a so-called traffic light system. Based on the risk of mortality of wild salmon populations due to life infestation, each of the 13 set up production areas is marked either 'green', 'yellow' or 'red' where only 'green' areas are permitted to grow biyearly. 'Yellow' areas are not allowed any growth and ‘red’ areas are even imposed biomass reductions (even though these were not enforced so far).

The first sale of new licenses/ new license capacity subsequent to the introduction of the regulation was a huge success where in total 50 companies acquired new production capacity of in total 23,306 tons for almost 4 billion NOK.

Having built up a broad understanding of how the Norwegian salmon aquaculture industry works and how it is regulated, thesis objectives 1 and 2 could be deemed completed. In order to be able to also fully comprehend the paradox detected by Pettersen Aubell & Haugen Hamarsland (2018), the literature review’s final two sections first introduced bioeconomic modeling in general. Second, the model extensions, the growth and price model, and the basic setup parameters of the net effect analysis by Pettersen Aubell & Haugen Hamarsland (2018) were summarized. This laid the ground for understanding their estimates of the farmers’ WTP for change in capacity which stand at odds with the enormous success of the 2018 production license sale.

Condensing the comprehensive amount of information and taking up Figure 16 once again, the reason(s) for the paradox have to lie in one of the parameters calculation of the maximized present value of total biomass over infinite rotations’ computation or other considerations. From these aspects, the following key research themes can be derived for the primary research part of this thesis:

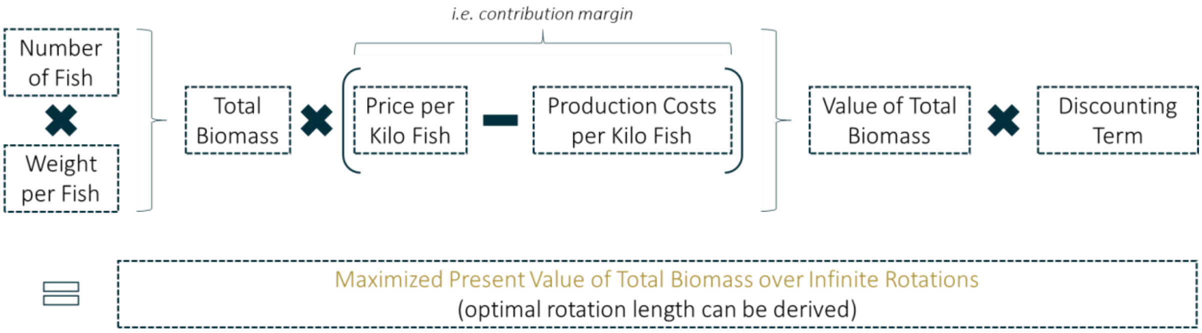
- Theme 1:
  Biomass Growth
- Theme 2:
  Market Price
- Theme 3:
  Production Costs
- Theme 4:
  Interest Rate
- Theme 5:
  Other Considerations

The key research themes are used as guiding themes and investigated in the following analysis and discussion.

3. Analysis & Discussion

Given Pettersen Aubell & Haugen Hamarsland's (2018) WTP for capacity increase calculations and the opposing 2018 production license sale raises questions about the motivations and economic reasoning behind the salmon grow-out farmers‘ investment decisions. This chapter will separately and systematically analyze the calculation components of the computation of the maximized present value of total biomass over infinite rotations in order to identify possible misconceptions or -assumptions. In particular, the most recent market and industry developments will be taken into consideration where developments of the last 12 to 18 months might potentially strengthen or weaken the farmers' assumptions from 12 to 18 months ago. This applies to a special degree to the market price and the production costs. Following the calculation order given by Figure 17, biomass growth, the market price, production costs, and the interest rate will be discussed consecutively. Furthermore, other considerations independent of the pure calculation will also receive their necessary attention.

Figure 17 – Calculatory Components of the Optimal Rotation Problem



Based on Asche & B Asche & Bjørndal, 2011

3.1 Biomass

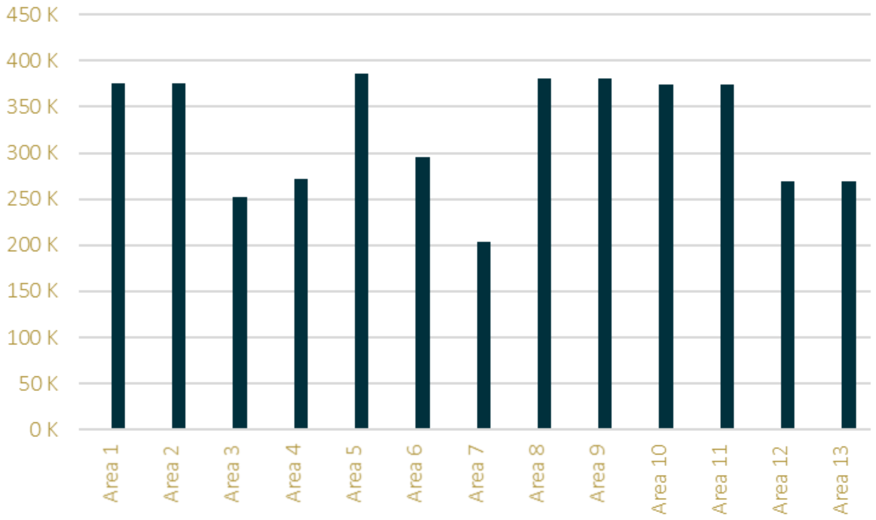
Total biomass is the product of the number of fish and the weight per fish at any given point in time. The number of fish consists of the number of recruits released to the ONPs at the beginning of the production cycle minus the loss of fish during the production cycle until slaughter. In between (from release until slaughter), the fish' growth depends on various factors that are tried to be captured in a growth function in order to be able to estimate the weight of the fish at any given point in time (i.e. months after release). Both the number of fish, as well as their growth will be discussed in the following two subsections. Discussing biomass, it remains that except for external, environmental conditions, this is the calculatory component with the largest opportunity to influence the final result.

3.1.1 Number of Fish

Recruits

The number of recruits is, compared to other influence factors, for sure the most accurately known aspect in the production process. It would be reasonable to assume that salmon grow-out farmers release as much smolt as possible, both from a capacity constraint perspective and within the limits of smolt supply. Whereas problems with the supply of smolt in terms of volume could not be identified, the utilization of MAB-capacity leaves room for discussion. According to the previously mentioned Bremnes model, farmers could exceed their given MAB for a limited time as long as the yearly average remains within MAB constraints. Nevertheless, this opportunity does not seem to be utilized to full capacity, yet. Given no constraints from a smolt-supply side, farmers could increase their number of recruits. Exceedance of the MAB limit towards the end of the production cycle could then be balanced by the volume that remained unutilized at the beginning of the production cycle due to low fish weight.

Figure 18 – Average Number of Recruits per License per Production Area, 2005 – 2016



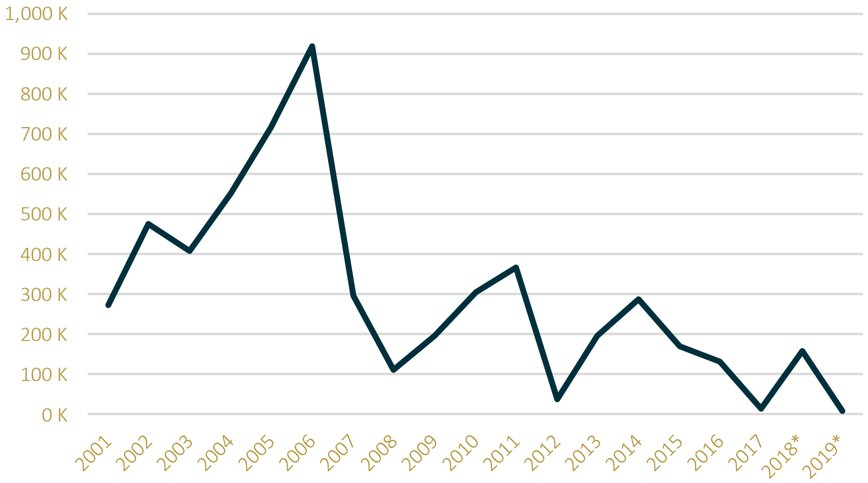
Looking at the average number of recruits per license per production area from 2005 to 2016 (based on the release data from the Norwegian Directorate of Fisheries) reveals significant differences between the different areas. In particular, the low numbers of recruits in area 12 and 13 seem somewhat illogical as licenses in these areas feature an over 20 % higher MAB

(945 tons over 780 tons) than the larger part of the rest of the country. Given the higher MAB, one would naturally assume that the farmers would also utilize this head start in consideration of the aggravated growth conditions due to a lower sea-water temperature average.

Loss of fish

As worked out in the literature review, the recruits released into the ONPs can be lost for two reasons: mortality or escape. Even though fish escapes receive enormous media attention, their volume is so small compared to fish mortality that it can be economically neglected. Figure 19 provides an overview of how technological progress led to a significant decrease in the numbers of escaped fish in the last two decades. Even if the reported numbers from 2017 would be underestimated fourfold, as suggested by Skilbrei, et al. (2015), it would still just be a little more than 60,000 escaped as opposed to 53 million dead fish in 2017. Ignoring any other costs associated with dead or escaped fish, the economic relevance of mortality exceeds the economic relevance of escapes by a factor of 850 in a worst-case escape scenario, in any other scenario even more.

Figure 19 – Reported Number of Escaped Atlantic Salmon in Norway, 2001 – 2019



*The numbers for 2018 and 2019 are interim results and are continously updated

Adapted from Fiskeridirektoratet, 2019a

Yet, a country-wide average mortality of about 20 % offers room for discussion and operational optimization. Mortality can have a variety of reasons that partly also interact with each other, and research on cause-specific mortality is rare. However, as there exists a consensus on the fact that salmon lice respectively delousing treatments are the most significant and influenceable factor in reducing mortality, a closer look should be taken at them.

The high mortality rates of 31 % and 25 % for thermal and mechanical treatments have recognizably increased the pressure on the development of lumpfish aquaculture, which is becoming “the salmon farming industry’s weapon of choice in the battle against sea lice” (Holmyard, 2018). According to an estimate from November 2018 by SeafoodSource, a leading source of seafood industry news, Norway currently hosts around 40 lumpfish producers, most of which are start-ups attracted by the enormous demand that is currently met by a very limited supply only. Given that larger lumpfish producers, e.g. Namdal Rensefisk, are also owned by several salmon grow-out farming companies such as Mowi, Midt Norsk Havbruk or Emilsen Fisk (Holmyard, 2018), these companies enjoy a clear competitive advantage over competitors who have to buy in lumpfish externally. Likewise, companies owning stakes in one or more lumpfish producing companies also have access to first-hand information on the most recent developments in, for example, broodstock units and breeding programs. This information advantage specifically could give salmon grow-out farmers an idea of when and to what extent the significant mortality rates could be reduced. Given the distinct results of Pettersen Aubell & Haugen Hamarsland’s (2018) robustness calculations for a 10 %-decrease in mortality, this would then give them a calculable reason for investments into increased production capacity.

Still, the efficacy of lumpfish remains subject to seasonal variations and also depends on other environmental factors (e.g. the availability of zooplankton as a source of food) such that future research will continue to show how fast mortality reductions in salmon aquaculture can be achieved. All industry players strive to push this project forward and lumpfish are expected to be the solution for the industries largest problem. To give a concluding example, the Norwegian Food Safety Authority is about to finish its final report for a ‘lumpfish-campaign’ that started in June 2018 and is supposed to deliver new insights into lumpfish deployment (Mattilsynet, 2019).

As a final note regarding mortality, from a pure model perspective, it is highly discussable in how far assuming constant mortality has an impact on the final WTP for increased capacity. Pettersen Aubell & Haugen Hamarsland (2018) did so by including the average mortality for each separate production area. However, it seems logical, that mortality varies a lot through the fish’ life cycle which, in turn, impacts the optimal rotation length and the maximized present value of total biomass over infinite rotations. Potentially, mortality varying through the year as a function of fish size and month as suggested by Guttormsen (2008) may be an alternative worth considering. Apart from Guttormsen (2008), also other authors chose to work with varying mortality rates across different age classes and mortality patterns they detected in their data sets (Liu, et al., 2013; Anderson, 2002). From the fishing industry, working with varying mortality depending on fish weight is also known (Plank, 2017). In contrast to the significant reduction of overall mortality through improved delousing by using lumpfish, this calculatory detail is, however, of minor importance.

3.1.2 Growth Function

Next to the pure number of fish, their weight is the second component of the calculation of total biomass. Whereas regarding mortality salmon grow-out farmers are at least to a certain extent dependable on the developments of the lumpfish industry (if they do not own a lumpfish business themselves), the growth process happening in the ONPs is their major opportunity to influence the financial outcome of their business.

As described in the literature review, Pettersen Aubell & Haugen Hamarsland (2018) created a growth model for the estimation of an individuals fish's weight. However, the model predicts the weight of an individual fish as a function of time (number of months after the release of a generation) and location (i.e. production area) only. Lice (average monthly number of lice per fish for a given location in a given month) and density (average number of fish per pen for a given location in a given month) were at least used as control variables.

All other components and influencing factors of the production process that were worked out in the literature review were, however, excluded from the model. In the following, their possible inclusion into an improved growth model will, therefore, be discussed with respect to how this would influence biomass predictions and the final estimation of the WTP for increased capacity. Additionally, the future development of these influencing factors will also be reflected upon. Any cost aspects of the components will be discussed in a later section.

Smolt Quality & Release

Smolt quality in general is difficult to quantify and difficult to numerically express. Of course, the prioritization of different traits in different breeding programs impacts the entire growth process of the fish until slaughter. Nevertheless, the inclusion of the factor 'smolt quality' seems unrealistic.

Looking at future developments, further improvements in the breeding programs can be expected even though this might be rather a question of years or decades than of weeks or months. On the other hand, taking the release of smolt, the timing could be integrated in order to account for the different growth developments of spring, autumn, and out-of-season smolts. This corresponds to the idea by Guttormsen (2008) who suggested to set up different growth functions/rates based on what time in the year the salmon are released.

Contemplating the topics of breeding (quality) and release together and holistically, it is to be expected that advancements in the breeding programs will lead to an increasing share of out-of-season smolts that will enable salmon grow-out-farmers to spread their production more flexibly throughout the calendar year. In total, this would enable the industry to reduce its peaks both in terms of prices and market supply and lead to a more balanced industry. Even though speculative, it can be assumed that this would increase companies' profitability and reduce certain cost parameters (e.g. slaughter costs as slaughtering could be distributed more evenly).

Feeding

Feeding was not included in Pettersen Aubell & Haugen Hamarsland's (2018) growth model, which seems a bit irritating at first sight. However, they assumed the optimal feeding decision to be included already in the estimated total biomass, presumably for simplicity reasons and accepted to leave out the optimal feeding choices. This coincides with literature findings and different Faustmann-based applications overlooked or deliberately opted against the inclusion of feeding choices (Asche & Guttormsen, 2001; Bjørndal, 1988). Others, again, tried to include feeding patterns (Heaps, 1993; Arnason, 1992).

As showed up in the literature review, the feeding regime (i.e. feeding rate, meal frequency, time of feeding and fasting), feeding technology as well as feed composition make the topic comprehensive, multilayered and complex. Therefore, an inclusion of all of them appears neither doable nor beneficial. Moreover, feed composition does not vary that much as the feed is produced by a highly consolidated salmonid feed industry. Further, the feed regime can be assumed to be highly confidential for most companies and such information should be considered as a business secret.

Feed quantity, however, is reported to the Norwegian Directorate of Fisheries as 'Feed consumption in the course of a month (number in kg)'. Pettersen Aubell & Haugen

Hamarsland's (2018), however, feared a simultaneity and endogeneity problem between weight and growth and decided, therefore, not to include feed quantity as an explanatory variable.

Looking forward, feeding technology is already quite advanced. Automation has been established to an adequate degree and cannot be expected to be substantially improved in the near future. With respect to feed composition, further nutritious improvements might be made although any assumptions in this biotechnological-oriented field would be purely speculative.

Environmental Conditions

Taking a closer look at the environmental conditions temperature, oxygen, salinity, and light, the external provision of oxygen and light has become common business practice and is not assumed to be able to contribute to considerable differences in growth or a significant competitive advantage.

Salinity, however, could for the sake of simplicity and practicability be differentiated between brackish water and full-strength seawater. Using a dummy variable, this aspect could be included in the regression. With the knowledge that salinity plays a particular role for more sensitive out-of-season smolts, an interaction term with a possible smolt release-variable (spring, autumn, out-of-season) could also provide for this circumstance.

Given that temperature is one of the most influenceable factors in regard to fish growth from a biological perspective, not including it appears negligent and utilizing the separate average sea temperature per week or month for each production area as provided by BarentsWatch (2019) would seem more logical. Plotting the weight per fish against sea temperature, Pettersen Aubell & Haugen Hamarsland (2018) obtained an ambiguous relationship and decided therefore not to include it into the regression. Considering that they did not closer specify which sea temperature data they used, rechecking this relationship seems worthwhile. Concerning global warming, increasing sea temperatures should be taken into consideration. Those would increase the value of northern Norwegian regions and potentially even decrease the value of southern Norwegian regions for them to become too warm and to exceed the optimal temperature of 13 °C on average.

Stocking Density

Stocking density could not be included by Pettersen Aubell & Haugen Hamarsland (2018) as the data set did not contain any information with respect to density. However, given that the data set contained the total number of fish per pen at a given location in a given period, correlating these values with the pens' size and hence adding density to the data set does not appear impossible. Especially with regard to the immense problems of closed containment systems with stocking density, a large amount of experience-based industry knowledge could be easily built up without being forced to require another substantial amount of (company-internal) data of the salmon grow-out-farmers. Given the stocking density's relevance to fish welfare and growth, this data could become highly valuable. As shown in the literature review, stocking density is limited by biological constraints and cannot be expected to be recognizably increased. Given upcoming animal welfare discussions (Jabr, 2018), stocking density should rather be expected to be further decreased in the years to come.

Diseases

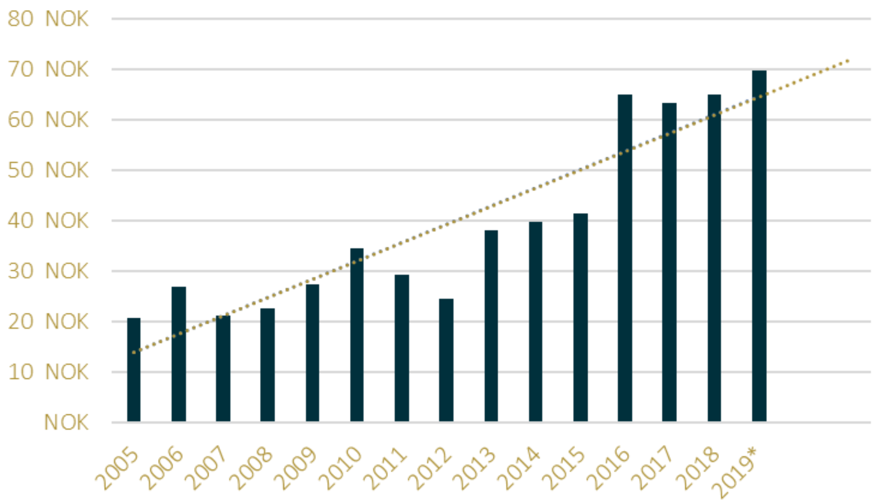
For the two main infectious diseases PD and ISA, the available data set contains too many missing values for most production areas to be useful for any correlation with biomass growth. However, the correlation of the lice data whose reporting salmon farmers are imposed upon could be expected to yield a negative relationship. In Pettersen Aubell & Haugen Hamarsland's (2018) plot, however, the opposite was the case. Although not covered by the investigated literature, a logical explanation for this curiosity might be that heavier (and hence more robust) fish are also able to bear more lice which then yields this misleading result. Yet, this variable remains difficult to include into regressions due to a persistent reverse causality between fish weight and lice infestation. Future lice infestation developments should be declining on the condition that the multifarious industry measures take effect. Likewise, the elaborately explained lumpfish developments should also contribute to a decreased mortality caused by lice infestation and treatments soon.

3.2 Market Price

In their robustness analysis, Pettersen Aubell & Haugen Hamarsland (2018) already found that a 10 % increase in the parameters of the price function would result in an average rise in WTP for increased capacity of 80.65 % for all production areas with a binding capacity constraint. This constitutes an enormous price sensitivity. Production Area 11 would feature the minimum WTP among all production areas (with a binding capacity constraint) with about 165 NOK per kg increased capacity and lie thereby 37.5 % above the profitability threshold of 120 NOK per kg increased capacity. This already indicates how much the decision of investing in increased production capacity depends on the salmon grow-out farmers' expectations of future market prices.

For their analysis, Pettersen Aubell & Haugen Hamarsland (2018) used inflation-adjusted NQSALMON price data for the period 2005 – 2016 (i.e. the same period as for the biomass data). The NQSALMON is "the weighted average of weekly reported sales prices and corresponding volumes in fresh Atlantic Superior Salmon, head-on-gutted (HOG), reported to Nasdaq Commodities by a panel of Norwegian salmon exporters and salmon producers with export license" (Nasdaq, 2019). Investigating the price development of the last 15 years reveals a significant (inflation-adjusted) price increase, especially since 2016, which is displayed in Figure 20.

Figure 20 – Average Atlantic Salmon Market Price per kg, 2005 – 2019



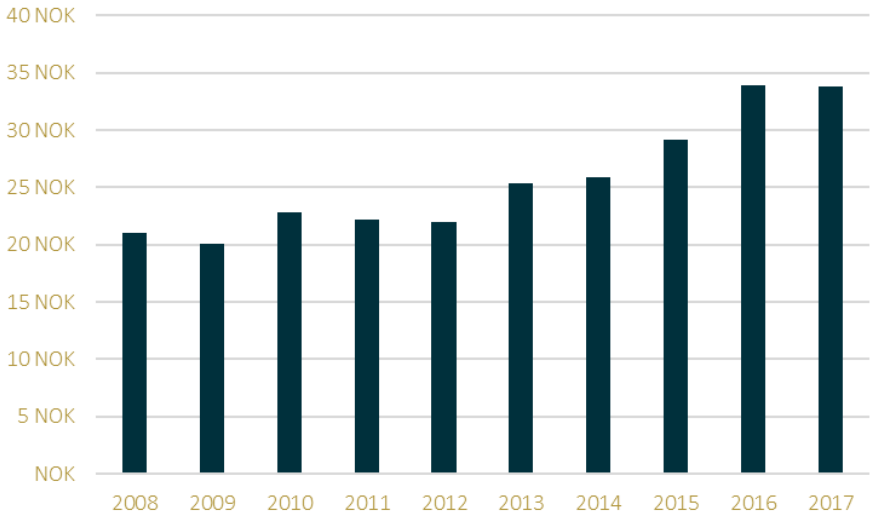
Based on Nasdaq, 2019; Statistisk sentralbyrå, 2019d

The price data from 2005 to 2016 used for the estimations made by Pettersen Aubell & Haugen Hamarsland (2018) feature a 12-years-average of 32.63 NOK opposed to 65.00 NOK for 2017 to calendar week 20 of 2019 (see Appendix F for a more detailed price analysis). Given the enormous price sensitivity that Pettersen Aubell & Haugen Hamarsland (2018) detected in their robustness analysis and the doubling of the average salmon price from 2017 until today (calendar week 20 of 2019) compared to the analyzed time period of 2005 to 2016 could be one of the main motivations behind the salmon grow-out farmers' investment decision. Of course, this conclusion implies the underlying assumption that the market price at least stays at the current level or even further increases.

3.3 Production Costs

Analogous to the market price, Pettersen Aubell & Haugen Hamarsland (2018) also conducted a robustness analysis for the production costs. As opposed to its market price elasticity, the WTP's cost elasticity turns out rather moderate. At a 10 % cost increase, the WTP for increased capacity would on average decrease by only 7 % for all production areas (with a binding capacity constraint). Even though their cost structure must evidently be highly heterogeneous, the salmon grow-out farmers cost sensitivity is in general considerably lower than their price sensitivity. Despite the costs limited effect on the farmers' investment decisions, a short exploration of recent production costs developments should be undertaken.

Figure 21 –Total Production Costs per kg Atlantic Salmon, 2008 – 2017



Based on Fiskeridirektoratet, 2018c

As illustrated by Figure 21, total costs have been rising during the last decade and increased from about 21 NOK per kg in 2008 to almost 34 NOK per kg in 2017 which corresponds to an increase of 61 % over 10 years. Even though this seems to be a lot at first sight, keeping in mind that the market price during the same period has increased by almost 280 % relativizes this cost development and lets it even appear neglectable.

Nevertheless, Pettersen Aubell & Haugen Hamarsland's (2018) decision to use a production cost of 22 NOK per kg seems somewhat unreasonable against the backdrop of recent developments where the current cost level exceeds this model parameter by about 50 %.

Looking in more detail into the separate cost elements (see also Appendix G), feed costs, making up almost 50% of the production costs, have increased by 45 % and are therefore one of the key drivers of the increasing total costs. Percentage-wise, 'Other costs' that mainly involve costs caused by fish health and environmental maintenance measures have increased the most, namely by 178 % (from almost 3 NOK per kg in 2008 to more than 8 NOK per kg in 2017). This cost increase can be mainly attributed to the change in lice treatments from chemical to thermal and mechanical measures. The development of further costs like insurance, labor, and depreciation can be ignored for the explanation of the farmers' investment behavior. Interestingly, the net financing costs per kg have decreased by almost 100 % from 0.95 NOK per kg in 2008 to 0.02 NOK per kg in 2017. This extreme drop in capital costs surely contributes to an enhanced attractiveness of long-term investments into production capacity but also facilities and equipment.

Finally, taking Pettersen Aubell & Haugen Hamarsland's (2018) growth and price function, the effect of changes in costs can be approximately quantified. Since a larger regression would exceed the scope and page limit of this thesis, the analysis is simplified as far as possible. To keep the computations straightforward, both the growth as well as the price function parameters are taken from the regression without fixed effects. For a benchmark, cost and discount rate are kept at the level of Pettersen Aubell & Haugen Hamarsland's (2018) analysis, 22 NOK per kg. For the mortality rate and the recruits per license, the average over all production areas is taken. A summary of all analysis parameters is provided in Table 8. For the computation of the WTP, the equation displayed Figure 17 is used:

Equation 3 – WTP Computation

$$WTP = \frac{Total\ Biomass \times (Price\ per\ kg\ - Cost\ per\ kg)}{e^{rt} - 1} \times \frac{1}{Total\ Biomass}$$

Solving this scenario, the highest net present value (NPV) of total biomass over infinite rotations assuming a biomass constraint of 780,000 tons per license is achieved after 14 months (see Appendix H). The respective WTP for gain in capacity is about 188 NOK per kg. Although already significantly higher than the average WTP for 2 % increased capacity calculated by Pettersen Aubell & Haugen Hamarsland's (2018), this value is still lower than the weighted average prices per ton achieved in the auctions in June and September 2018 (see Table 3).

Table 8 – Norwegian – WTP Analysis Parameters

Growth Function	
Time^2 (β_1)	0.0275
Time^3 (β_2)	-0.000885
Mortality Rate	0.0177
Recruits per License	323,534

Price function	
Constant (β_1)	23.48
Weight (β_2)	5.557
Weight^2 (β_3)	-0.489

Model Parameters	
Cost per kg	NOK 22.00
Discount rate	6.00%

To conclude the cost analysis and illustrate the WTP’s sensitivity to this calculatory component, Equation 3 can be solved for ‘Cost per kg’ and calculated for a WTP of 195 NOK per kg, the approximated weighted average price achieved in the main auction from June 2018.

Equation 4 – WTP Computation solved for Cost per kg

$$Cost\ per\ kg = Price\ per\ kg\ -\ WTP \times (e^{rt} - 1)$$

To obtain a WTP of 195 NOK per kg, a cost of 21.51 would be needed. Hence costs would need to decrease by about 0.49 NOK only.

3.4 Interest Rate

Investigating investment decision making in a business context always brings up the topic of opportunity cost which in this case can be described as the interest that could be earned in other ventures on the investment taken in one’s own business. For this purpose and to calculate the present value of the investment of all future rotations, Asche & Bjørndal (2011) built a discount factor into their calculations. Adopting this discount factor to reflect the expected ROI in the Norwegian market, Pettersen Aubell & Haugen Hamarsland (2018) set the interest rate to 6 % based on the market assessment by NHH associate professor Finn Kinserdal (2017).

As for the market price and the production costs, they also performed a robustness analysis for changes in the interest rate and found a reduced WTP of about 40 % for an increase of 4 % in interest rate. An increasing interest rate decreases the present value of future rotations as future profits are discounted at a higher rate. Conversely, a lower interest rate increases the present value of future rotations (and hence WTP for increased capacity). PwC (2018) conducts a study with the title 'The risk premium in the Norwegian market' since seven years now and rather observes a market risk premium of around 5 %, as displayed in Table 9.

Table 9 – Norwegian Market Risk Premium, 2012 – 2018

	2012	2013	2014	2015	2016	2017	2018	ø
Weighted average	5.0%	5.1%	5.2%	5.2%	4.9%	5.0%	5.0%	5.1%
Median	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
First quartile	4.0%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.4%
Third quartile	5.5%	5.5%	5.5%	6.0%	5.5%	5.4%	5.1%	5.5%

Adapted from PwC, 2018

Taking the market risk premium from the analyses by PwC (2018) would suggest a higher WTP for increased capacity among salmon grow-out farmers and hence contribute to explaining the production license sale paradox.

To conclude the interest rate analysis and illustrate the WTP's sensitivity to this calculatory component, similar to the cost calculation, Equation 3 can also be solved for the 'Interest Rate' and calculated for a WTP of 195 NOK per kg.

Equation 5 – WTP Computation solved for the Interest Rate

$$Interest\ Rate = \frac{\ln\left(\frac{Price\ per\ kg\ - Cost\ per\ kg + WTP}{WTP}\right) \times 12}{t}$$

To obtain a WTP of 195 NOK per kg, an interest rate of 5.8 % would be needed, hence the interest rate would need to decrease by about 0.2 %. Given the PwC (2018) analysis from above, this criteria would already be fulfilled.

As a final remark in regard to the discount term, it should be considered that this interest rate is highly dependent on each and every market and can hardly be generalized for an entire economy. Going back to the roots of bioeconomic modeling in aquaculture and taking forestry and timber production as an illustrating example, this industry discounts future rotations usually at an interest rate of 2 %. In a relatively recent profitability analysis of timber production, Coordes (2013), for example, used a 1 % and a 4 % interest rate for his computations. Given the comparably long production cycles in forestry of up to 100 years, lower interest rates in this industry that exhibits similar mechanics as aquaculture become explainable. Nevertheless, this example is meant to raise awareness for the interest rate's industry dependence and point out the disputability of any market risk premium in this respect.

3.5 Other Considerations

Having analyzed all calculatory components of the computation of the maximized present value of total biomass over infinite rotations, this analysis is concluded by discussing some other possible explanations for the farmer's investment behavior. Even if not directly incorporable into bioeconomic models, the following aspects might also have an influence on the salmon grow-out farmers' investment decision making. Having discussed the market risk premium, general risk aversion seems a suitable topic to start with.

Risk Aversion

Going one step back to the market risk premium, arguing that every industry has its own mechanics and therefore also its own discount rate, one could also take this one step further and argue that every single salmon grow-out business has its own discount rate depending on the business' risk aversion. Assuming that a low risk aversion corresponds to a higher discount rate, this would in general imply more risk averse farmers who rather prefer to invest into less risky production capacity than into other riskier ventures. For example, a risk-averse salmon grow-out farmer might choose to invest his capital into production licenses with a lower but relative guaranteed ROI, rather than into a stock that may have high expected returns, but also involves a higher risk of losing value. Furthermore, one could also consider risk aversion from a temporal point of view and interpret the sales success as a preference of the farmers for secure growth today over insecure growth in the future. Summarizing this in a term, the farmers would then exhibit a 'the earlier, the better'-mentality.

Maximum Inter-Regional Biomasses

As mentioned previously, companies that have vertically integrated the processing of substantial shares of their stock into their business operations are allowed to deploy their allocated MAB throughout several geographic regions. Given this opportunity, one could guess that large companies who are aware of their additional freedom with regard to capacity operationalization in different areas allow for this in their investment planning and capital budgeting. Recalling that this exceptional regulation was drawn up in order to secure economically important jobs in the processing sector, it appears unrealistic that the government will cancel the regulation upon excessive overuse by the respective firms. Therefore, some of the increased capacity bought in regions with a WTP below 120 NOK/kg might have been bought for regions were capacity operationalization is actually profitable.

Threat of New Entrants

Given the overall positive industry situation (rising market prices, solution for the salmon lice challenge in sight, etc.), a final aspect worth to consider might be the potential market entry of additional firms which might be attracted by the promising market conditions. Also in consideration of new production technologies such as CCSs or offshore aquaculture, current market players might fear competitive rivalry to become increasingly fierce triggered by a growing threat of new entrants, as modeled by strategy and competition guru Michael E. Porter (1979). This threat might lead to a disproportional desire to secure freely available production capacity from potential competitors irrespective of one own's concrete business situation, both geographically and financially. If this strategy is deployed in reality or not is hard to estimate and would have to be researched qualitatively by interviewing employees who are responsible for the investment decision making in their business. Recalling the estimated MAB Utilization from Figure 10, which illustrated the unutilized production capacity, could indicate that salmon grow-out farmers buy licenses but do not produce at the maximum capacity, yet. From this figure alone, it is, however, difficult to say if this happens for strategic reasons or just due to operational mismanagement.

4. Conclusions & Recommendations

This thesis aimed at explaining salmon grow-out farmers' motivation and economic reasoning behind their investment behavior for production licenses under the Norwegian traffic light system. For this purpose, industry literature was critically reviewed and extensively examined on salmon market mechanisms and the production process with a special focus on the decision variables of salmon grow-out farmers (Objective 1). Secondly, the regulation of the Norwegian salmon aquaculture with a special focus on the role of production licenses, the 'Product Area Regulation' and the 2018 production license sale were also critically reviewed and extensively examined (Objective 2). Used as guiding themes for the analysis and discussion, the following five influence variables could be derived from the literature review:

- Theme 1: Biomass Growth
- Theme 2: Market Price
- Theme 3: Production Costs
- Theme 4: Interest Rate
- Theme 5: Other Considerations

The findings of the critical analysis and discussion of the salmon grow-out farmers' motivation and economic reasoning behind their investment behavior for production licenses under the Norwegian traffic light system can be summarized as follows:

First, biomass has been discussed regarding the pure number of fish and their weight, usually determined by a growth function. In terms of the number of fish, the number of recruits offers some room for improvement of MAB exploitation through better utilization of the Bremnes model. Whereas the number of escapes can economically be neglected, future reductions in mortality associated with lice treatments could have a significant impact on the sector's profitability. As soon as lumpfish aquaculture is established, mortality caused by lice treatments is expected to significantly decrease. Future improvements in breeding programs could enable farmers to release the fish more evenly distributed over the year. This would alleviate the substantial price fluctuations in relative prices for different weight classes and could give the industry more stability. Global warming is predicted to increase the value of northern Norwegian regions and sea-water temperature increase should be accounted for when modeling investment behavior in the industry. Stocking density is rather about to become an issue for land-based and offshore aquaculture. Since licensing for these two future-oriented technologies is, however, handled separately by the Norwegian government, this aspect can be disregarded for the analysis of the investment behavior for ‘traditional’ production licenses.

Second, the analysis the of most recent market price data has shown an overly positive development with a significant jump in price in 2016. The average price for the last two and a half years has doubled compared to the average price for the time period 2005 – 2016, the time period of the price data used by Pettersen Aubell & Haugen Hamarsland (2018). Taking into account future market price developments seems therefore essential for the evaluation of a future-oriented investment decision.

Thirdly, production costs’ influence on the farmer’s WTP could be shown through various calculatory examples and illustrations. Like the market price, production costs also increased in recent years. However, a cost increase of 61 % over the last ten years is rather moderate in comparison to a market price increase of almost 280 % for the same period. Solving the lice problem by establishing lumpfish aquaculture will not only decrease mortality but also lower production costs.

Fourthly, assumptions about the interest rate by which future rotations are discounted were shown to have a tremendous influence on the WTP for capacity increase. Therefore, simply assuming the interest rate to resemble the country-wide market risk premium has to be questioned. Rather, the industry’s characteristics as well as risk aversion and attitudes towards uncertainty must be considered when making assumptions about the discount rate of the long-term investment ‘production license’.

Fifthly and lastly, large companies can operationalize their company-wide MAB in different areas. This might potentially distort the analyses made to a certain extent but does not question fundamental conclusions made. However, it seems reasonable to introduce a cap for maximum inter-regional biomasses to avoid reducing the traffic light system to absurdity. Also, over-proportional purchasing as a measure to prevent new companies from entering the lucrative-seeming market has to be considered.

Synthesizing, a common characteristic inherent to all conclusions is their future-directedness. The whole literature building bioeconomic modeling on Faustmann’s formula assumes that the parameters do not change over time. However, the paradox raised by Pettersen Aubell & Haugen Hamarsland’ (2018) analysis in comparison with the 2018 production license sale revealed how essential the inclusion of assumptions about future developments is.

5. Research Constraints & Future Research

Aiming to explain salmon grow-out farmers' motivation and economic reasoning behind their investment behavior for production licenses under the Norwegian traffic light system, the original thesis design provided for the comprehensive industry analysis to be supplemented by qualitative research. For this purpose, the 2018 production license sale has been analyzed to a significantly greater extent than what was covered in this thesis. With the aim to interview investment decision-makers of relevant salmon farming companies, a detailed record of all transactions of the 2018 production license sale was created. This overview can be found in Appendix D. Since the paradox was most significant for Production Area 10 and Production Area 11, a separate overview was created for the transactions in these areas only. This overview can be found in Appendix E.

Despite best efforts over a time period of two months with in total 25 contacted salmon farming companies, it was not possible to get hold of interview partners as originally planned. A scheduled interview with the industry experts from a Bergen-based network for and owned by small and medium-sized salmon farming companies was canceled due to sickness in the last moment. The tight working schedule of the experts prevented the realization of a second interview date. Due to time constraints, it was then decided to opt for an extended literature. Provided less tight time constraints than featured by the semester schedule this work had to follow, obtaining first-hand insights and opinions on the paradox explanations identified in this industry analysis appears both realizable as well as highly interesting. By interviewing investment decision-makers on the themes that were worked out in this thesis, the assumptions and critical considerations made in the analysis of this thesis could be strengthened and confirmed or questioned and disproved.

Also, this thesis focused on the production licenses for the established 'traditional' production locations. Land-based and offshore aquaculture have been introduced in this thesis as two promising future technologies that bear the potential to increase the production volume of the industry substantially in the years to come. License-wise, both technologies are, however, handled separately from the 'traditional' production licenses. Since most of the current innovative production sites are run as pioneering projects, the majority is legalized by development licenses. With a growing number of land-based and offshore aquaculture operations, authorities will have to find a way to regulate these two new industry branches. Therefore, the licensing of land-based and offshore aquaculture might be another field of research worth more detailed academic investigation that was not realizable within the available page count of this thesis.

To conclude, although the author has lived in Norway for almost one full year and has an effective operational command of Norwegian, cultural and linguistic bias in the perception of this highly country-specific research field cannot be fully excluded. To illustrate, limitations in reading comprehension could have led to misinterpretation of Norwegian sources. Further, the investment behavior for production licenses of Norwegian salmon grow-out farmers has been interpreted and judged by standards inherent to the author's German cultural background. To prevent any substantial misinterpretations, the thesis results have been discussed with Norwegian fellows and backed up by the inclusion of a considerable number of English-language sources written by Norwegian industry experts.

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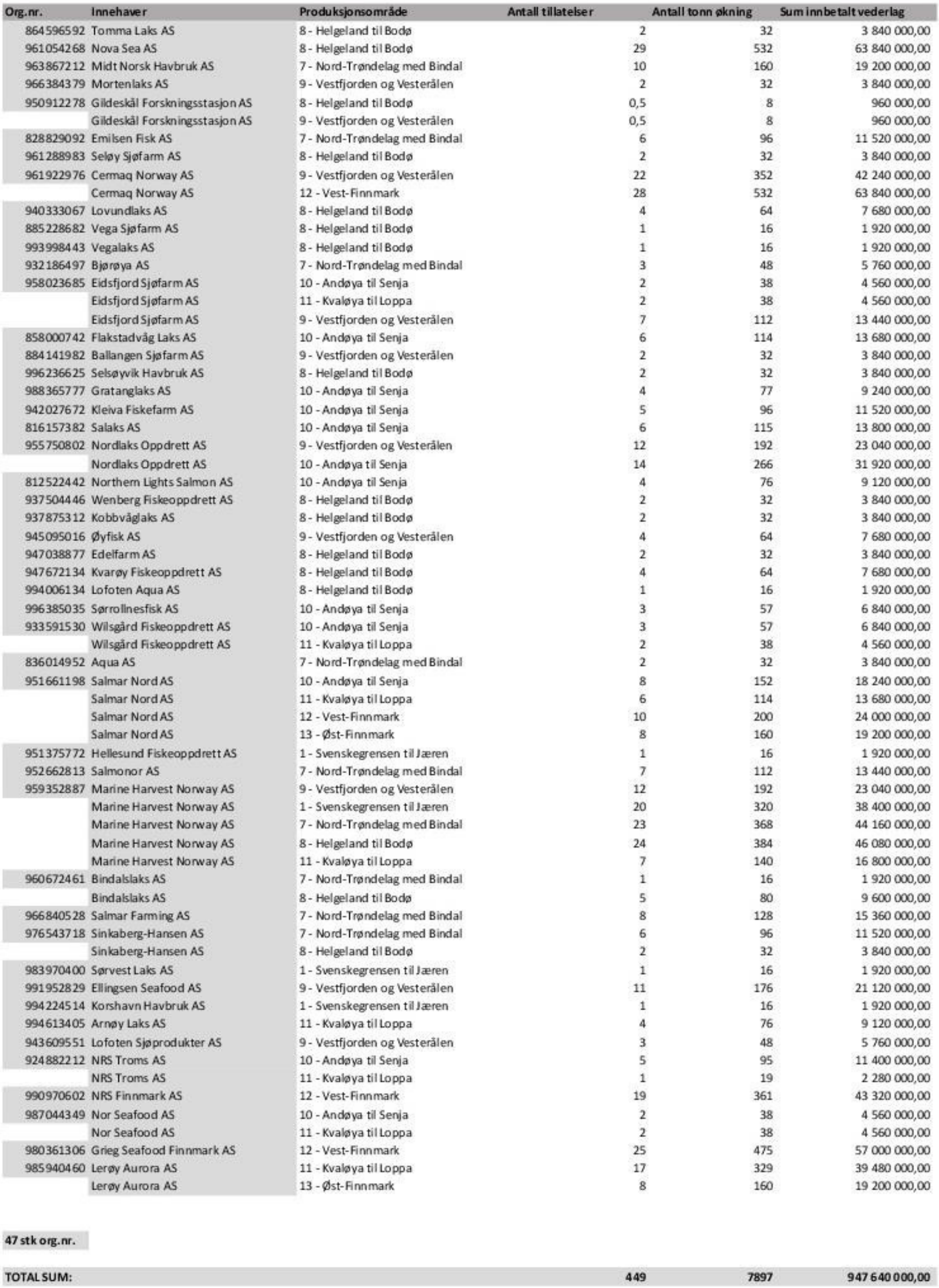
Appendices

Appendix A – Salmon Companies granted 2 % Growth in January 2018



Org.nr.	Innehaver	Produksjonsområde	Antall tillatelser	Antall tonn økning	Sum innbetalt vederlag
864596592	Tomma Laks AS	8 - Helgeland til Bodø	2	32	3 840 000,00
961054268	Nova Sea AS	8 - Helgeland til Bodø	29	532	63 840 000,00
963867212	Midt Norsk Havbruk AS	7 - Nord-Trøndelag med Bindal	10	160	19 200 000,00
966384379	Mortenlaks AS	9 - Vestfjorden og Vesterålen	2	32	3 840 000,00
950912278	Gildeskål Forskningsstasjon AS	8 - Helgeland til Bodø	0,5	8	960 000,00
	Gildeskål Forskningsstasjon AS	9 - Vestfjorden og Vesterålen	0,5	8	960 000,00
828829092	Emilsen Fisk AS	7 - Nord-Trøndelag med Bindal	6	96	11 520 000,00
961288983	Seløy Sjøfarm AS	8 - Helgeland til Bodø	2	32	3 840 000,00
961922976	Cermaq Norway AS	9 - Vestfjorden og Vesterålen	22	352	42 240 000,00
	Cermaq Norway AS	12 - Vest-Finnmark	28	532	63 840 000,00
940333067	Lovundlaks AS	8 - Helgeland til Bodø	4	64	7 680 000,00
885228682	Vega Sjøfarm AS	8 - Helgeland til Bodø	1	16	1 920 000,00
993998443	Vegalaks AS	8 - Helgeland til Bodø	1	16	1 920 000,00
932186497	Bjørøya AS	7 - Nord-Trøndelag med Bindal	3	48	5 760 000,00
958023685	Eidsfjord Sjøfarm AS	10 - Andøya til Senja	2	38	4 560 000,00
	Eidsfjord Sjøfarm AS	11 - Kvaløya til Loppa	2	38	4 560 000,00
	Eidsfjord Sjøfarm AS	9 - Vestfjorden og Vesterålen	7	112	13 440 000,00
858000742	Flakstadvåg Laks AS	10 - Andøya til Senja	6	114	13 680 000,00
884141982	Ballangen Sjøfarm AS	9 - Vestfjorden og Vesterålen	2	32	3 840 000,00
996236625	Selsøyvik Havbruk AS	8 - Helgeland til Bodø	2	32	3 840 000,00
988365777	Gratanglaks AS	10 - Andøya til Senja	4	77	9 240 000,00
942027672	Kleiva Fiskefarm AS	10 - Andøya til Senja	5	96	11 520 000,00
816157382	Salaks AS	10 - Andøya til Senja	6	115	13 800 000,00
955750802	Nordlaks Oppdrett AS	9 - Vestfjorden og Vesterålen	12	192	23 040 000,00
	Nordlaks Oppdrett AS	10 - Andøya til Senja	14	266	31 920 000,00
812522442	Northern Lights Salmon AS	10 - Andøya til Senja	4	76	9 120 000,00
937504446	Wenberg Fiskeoppdrett AS	8 - Helgeland til Bodø	2	32	3 840 000,00
937875312	Kobbvåglaks AS	8 - Helgeland til Bodø	2	32	3 840 000,00
945095016	Øyfisk AS	9 - Vestfjorden og Vesterålen	4	64	7 680 000,00
947038877	Edelfarm AS	8 - Helgeland til Bodø	2	32	3 840 000,00
947672134	Kvarøy Fiskeoppdrett AS	8 - Helgeland til Bodø	4	64	7 680 000,00
994006134	Lofoten Aqua AS	8 - Helgeland til Bodø	1	16	1 920 000,00
996385035	Sørrollnesfisk AS	10 - Andøya til Senja	3	57	6 840 000,00
933591530	Wilsgård Fiskeoppdrett AS	10 - Andøya til Senja	3	57	6 840 000,00
	Wilsgård Fiskeoppdrett AS	11 - Kvaløya til Loppa	2	38	4 560 000,00
836014952	Aqua AS	7 - Nord-Trøndelag med Bindal	2	32	3 840 000,00
951661198	Salmar Nord AS	10 - Andøya til Senja	8	152	18 240 000,00
	Salmar Nord AS	11 - Kvaløya til Loppa	6	114	13 680 000,00
	Salmar Nord AS	12 - Vest-Finnmark	10	200	24 000 000,00
	Salmar Nord AS	13 - Øst-Finnmark	8	160	19 200 000,00
951375772	Hellesund Fiskeoppdrett AS	1 - Svenskegrensen til Jæren	1	16	1 920 000,00
952662813	Salmonor AS	7 - Nord-Trøndelag med Bindal	7	112	13 440 000,00
959352887	Marine Harvest Norway AS	9 - Vestfjorden og Vesterålen	12	192	23 040 000,00
	Marine Harvest Norway AS	1 - Svenskegrensen til Jæren	20	320	38 400 000,00
	Marine Harvest Norway AS	7 - Nord-Trøndelag med Bindal	23	368	44 160 000,00
	Marine Harvest Norway AS	8 - Helgeland til Bodø	24	384	46 080 000,00
	Marine Harvest Norway AS	11 - Kvaløya til Loppa	7	140	16 800 000,00
960672461	Bindalslaks AS	7 - Nord-Trøndelag med Bindal	1	16	1 920 000,00
	Bindalslaks AS	8 - Helgeland til Bodø	5	80	9 600 000,00
966840528	Salmar Farming AS	7 - Nord-Trøndelag med Bindal	8	128	15 360 000,00
976543718	Sinkaberg-Hansen AS	7 - Nord-Trøndelag med Bindal	6	96	11 520 000,00
	Sinkaberg-Hansen AS	8 - Helgeland til Bodø	2	32	3 840 000,00
983970400	Sørvest Laks AS	1 - Svenskegrensen til Jæren	1	16	1 920 000,00
991952829	Ellingsen Seafood AS	9 - Vestfjorden og Vesterålen	11	176	21 120 000,00
994224514	Korshavn Havbruk AS	1 - Svenskegrensen til Jæren	1	16	1 920 000,00
994613405	Arnøy Laks AS	11 - Kvaløya til Loppa	4	76	9 120 000,00
943609551	Lofoten Sjøprodukter AS	9 - Vestfjorden og Vesterålen	3	48	5 760 000,00
924882212	NRS Troms AS	10 - Andøya til Senja	5	95	11 400 000,00
	NRS Troms AS	11 - Kvaløya til Loppa	1	19	2 280 000,00
990970602	NRS Finnmark AS	12 - Vest-Finnmark	19	361	43 320 000,00
987044349	Nor Seafood AS	10 - Andøya til Senja	2	38	4 560 000,00
	Nor Seafood AS	11 - Kvaløya til Loppa	2	38	4 560 000,00
980361306	Grieg Seafood Finnmark AS	12 - Vest-Finnmark	25	475	57 000 000,00
985940460	Lerøy Aurora AS	11 - Kvaløya til Loppa	17	329	39 480 000,00
	Lerøy Aurora AS	13 - Øst-Finnmark	8	160	19 200 000,00
47 stk org.nr.					
TOTAL SUM:			**449**	**7897**	**947 640 000,00**

Appendix B – Auctioned Licenses 18. – 20.06.2018

Production Area No.	**Production Area**	**Bidder**	**# tons**	**Price per ton**	**Total Price**
1	Svenskegrensen til Jæren	Eide Fjordbruk AS	100	132.000	13.200.000
1	Svenskegrensen til Jæren	Marine Harvest Norway AS	493	132.000	65.076.000
7	Nord-Trøndelag med Bindal	Emilsen Fisk AS	400	226.000	90.400.000
7	Nord-Trøndelag med Bindal	Norsk Havbrukssenter Oppdrett AS	265	226.000	59.890.000
7	Nord-Trøndelag med Bindal	Midt Norsk Havbruk AS	600	210.000	126.000.000
7	Nord-Trøndelag med Bindal	Midt Norsk Havbruk AS	180	208.000	37.440.000
7	Nord-Trøndelag med Bindal	Salmar Farming AS	183	210.000	38.430.000
7	Nord-Trøndelag med Bindal	Salmar Farming AS	260	208.000	54.080.000
8	Helgaland til Bodø	Lovundlaks AS	1.850	252.000	466.200.000
8	Helgaland til Bodø	Edelfarm AS	604	247.000	149.188.000
9	Vestfjorden og Vesterålen	Ballangen Sjøfarm AS	200	232.000	46.400.000
9	Vestfjorden og Vesterålen	Ballangen Sjøfarm AS	50	227.000	11.350.000
9	Vestfjorden og Vesterålen	Cermaq Norway AS	2.000	232.000	464.000.000
9	Vestfjorden og Vesterålen	Cermaq Norway AS	30	227.000	6.810.000
9	Vestfjorden og Vesterålen	Eidsfjord Sjøfarm AS	200	232.000	46.400.000
9	Vestfjorden og Vesterålen	Lofoten Sjøprodukter AS	53	232.000	12.296.000
9	Vestfjorden og Vesterålen	Lofoten Sjøprodukter AS	20	227.000	4.540.000
9	Vestfjorden og Vesterålen	Lofoten Sjøprodukter AS	32	233.000	7.456.000
10	Andøya til Senja	Eidsfjord Sjøfarm AS	517	164.000	84.788.000
10	Andøya til Senja	Eidsfjord Sjøfarm AS	400	166.000	66.400.000
10	Andøya til Senja	Marine Harvest Norway AS	806	164.000	132.184.000
10	Andøya til Senja	Marine Harvest Norway AS	170	166.000	28.220.000
10	Andøya til Senja	Marine Harvest Norway AS	12	164.000	1.968.000
10	Andøya til Senja	Salmar Farming AS	333	164.000	54.612.000
10	Andøya til Senja	Stingray Marine Solutions AS	25	164.000	4.100.000
11	Kvaløya til Loppa	Eidsfjord Sjøfarm AS	357	163.000	58.191.000
11	Kvaløya til Loppa	Marine Harvest Norway AS	566	163.000	92.258.000
11	Kvaløya til Loppa	Marine Harvest Norway AS	4	161.000	644.000
11	Kvaløya til Loppa	NRS Finnmark AS	300	163.000	48.900.000
11	Kvaløya til Loppa	Salmar Farming AS	333	163.000	54.279.000
11	Kvaløya til Loppa	Salmar Farming AS	10	161.000	1.610.000
12	Vest-Finnmark	Cermaq Norway AS	1.200	166.000	199.200.000
12	Vest-Finnmark	Marine Harvest Norway AS	832	166.000	138.112.000
12	Vest-Finnmark	Marine Harvest Norway AS	30	165.000	4.950.000
12	Vest-Finnmark	Marine Harvest Norway AS	17	163.000	2.771.000
12	Vest-Finnmark	NRS Finnmark AS	400	166.000	66.400.000
12	Vest-Finnmark	NRS Finnmark AS	100	165.000	16.500.000
12	Vest-Finnmark	Salmar Farming AS	333	166.000	55.278.000
12	Vest-Finnmark	Salmar Farming AS	47	163.000	7.661.000
13	Øst-Finnmark	Salmar Farming AS	316	158.000	49.928.000
13	Øst-Finnmark	Salmar Farming AS	317	149.000	47.233.000
SUM / WEIGHTED AVERAGE			**14.945**	**195.071**	**2.915.343.000**

Appendix C – Auctioned Licenses 17.09.2018

License Number	Production Area Number	Production Area	Winning bidder	# tons	Winning bid	Price per ton
1	1	Svenskegrensen til Jæren	Eide Fjordbruk AS	16	2.120.000	132.500
2	7	Nord-Trøndelag med Bindal	Midt-Norsk Havbruk AS	100	20.600.000	206.000
3	7	Nord-Trøndelag med Bindal	Midt-Norsk Havbruk AS	45	9.270.000	206.000
4	8	Helgaland til Bodø	Selsøyvik Havbruk AS	100	24.519.012	245.190
5	8	Helgaland til Bodø	Selsøyvik Havbruk AS	100	24.618.023	246.180
6	10	Andøya til Senja		40		
7	11	Kvaløya til Loppa	Marine Harvest Norway AS	2	258.000	129.000
8	12	Vest-Finnmark		11		
SUM / WEIGHTED AVERAGE				**414**	**81.385.035**	**196.582**

Appendix D – Total Overview 2018 Production License Sale

	Fixed-Price Sale January 2018									**Auction June 2018**									**Auction September 2018**									**Σ**
	1	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Σ**	**1**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Σ**	**1**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Σ**	
Aqua AS		32							32																			32
Arnøy Laks AS						76			76																			76
Ballangen Sjøfarm AS				32					32				250					250										282
Bindallaks AS		16	80						96																			96
Bjørøya AS		48							48																			48
Cermaq Norway AS				352			532		884				2,030			1,200		3,230										#####
Edelfarm AS			32						32			604						604										636
Eide Fjordbruk AS										100								100	16								16	116
Eidsfjord Sjøfarm AS				112	38	38			188				200	917	357			1,474										#####
Ellingsen Seafood AS				176					176																			176
Emilsen Fisk AS		96							96		400							400										496
Flakstadvåg Laks AS					114				114																			114
Gildeskål Forskningsstasjon AS			8	8					16																			16
Gratanglaks AS					77				77																			77
Grieg Seafood Finnmark AS							475		475																			475
Hellesund Fiskeoppdrett AS	16								16																			16
Kleiva Fiskefarm AS					96				96																			96
Kobbvåglaks AS			32						32																			32
Korshavn Havbruk AS	16								16																			16
Kvarøy Fiskeoppdrett AS			64						64																			64
Lerøy Aurora AS						329		160	489																			489
Lofoten Aqua AS			16						16																			16
Lofoten Sjøprodukter AS				48					48				105					105										153
Lovundlaks AS			64						64			1,850						1,850										#####
Marine Harvest Norway AS	320	368	384	192		140			1,404	493				988	570	879		2,930						2			2	#####
Midt-Norsk Havbruk AS		160							160		780							780		145							145	#####
Mortenlaks AS				32					32																			32
Nor Seafood AS					38	38			76																			76
Nordlaks Oppdrett AS				192	266				458																			458
Norsk Havbrukssenter Oppdrett AS											265							265										265
Northern Lights Salmon AS					76				76																			76
Nova Sea AS			532						532																			532
NRS Finnmark AS							361		361						300	500		800										#####
NRS Troms AS					95	19			114																			114
Øyfisk AS				64					64																			64
Salaks AS					115				115																			115
Salmar Farming AS		128							128		443			333	343	380	633	2,132										#####
Salmar Nord AS					152	114	200	160	626																			626
Salmonor AS		112							112																			112
Seløy Sjøfarm AS			32						32																			32
Selsøyvik Havbruk AS			32						32												200						200	232
Sinkaberg-Hansen AS		96	32						128																			128
Sørrollnesfisk AS					57				57																			57
Sørvest Laks AS	16								16																			16
Stingray Marine Solutions AS														25				25										25
Tomma Laks AS			32						32																			32
Vega Sjøfarm AS			16						16																			16
Vegalaks AS			16						16																			16
Wenberg Fiskeoppdrett AS			32						32																			32
Wilsgård Fiskeoppdrett AS					57	38			95																			95
SUM	368	1,056	1,404	1,208	1,181	792	1,568	320	**7,897**	593	1,888	2,454	2,585	2,263	1,570	2,959	633	**14,945**	16	145	200		-	2	-		**363**	**23,205**

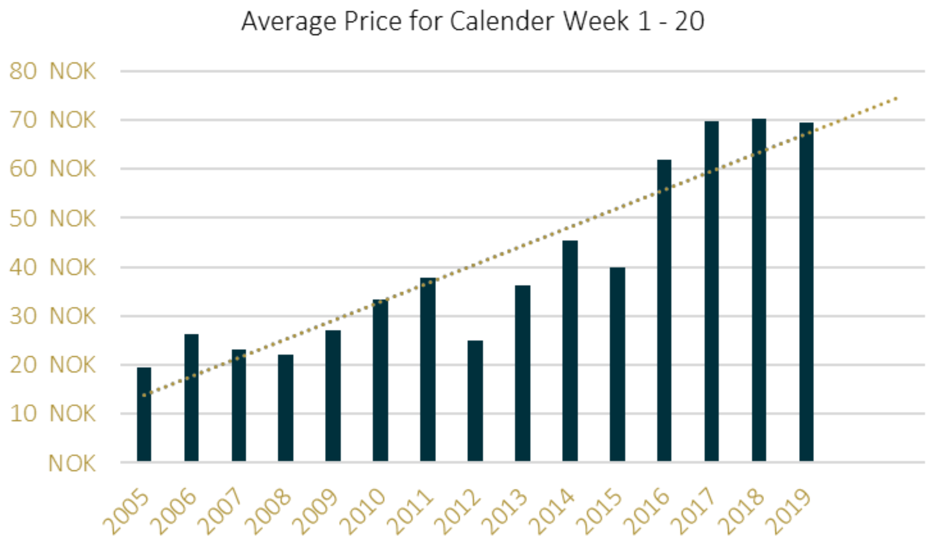
Appendix E – Production License Sale 2018 – Production Area 10 & 11

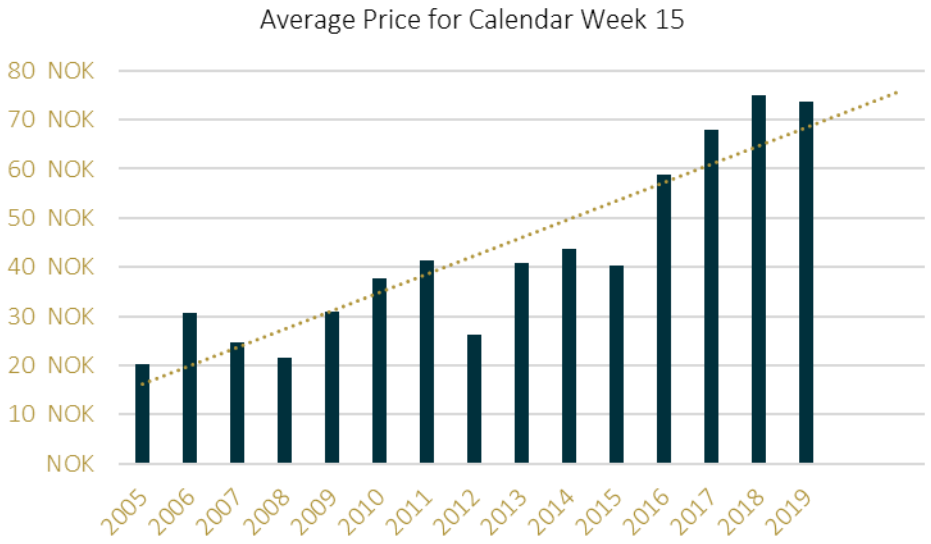
	Fixed-Price Sale January 2018		**Auction June 2018**		**Auction September 2018**		**Total Biomass Bought**	**% Production Areas 10 & 11**
	10	**11**	**10**	**11**	**10**	**11**		
Arnøy Laks AS	0	76	0	0	0	0	76	**100%**
Eidsfjord Sjøfarm AS	38	38	917	357	0	0	1662	81%
Flakstadvåg Laks AS	114	0	0	0	0	0	114	**100%**
Gratanglaks AS	77	0	0	0	0	0	77	**100%**
Kleiva Fiskefarm AS	96	0	0	0	0	0	96	**100%**
Lerøy Aurora AS	0	329	0	0	0	0	489	67%
Marine Harvest Norway AS	0	140	988	570	0	2	4336	39%
Nor Seafood AS	38	38	0	0	0	0	76	**100%**
Nordlaks Oppdrett AS	266	0	0	0	0	0	458	58%
Northern Lights Salmon AS	76	0	0	0	0	0	76	**100%**
NRS Finnmark AS	0	0	0	300	0	0	1161	26%
NRS Troms AS	95	19	0	0	0	0	114	**100%**
Salaks AS	115	0	0	0	0	0	115	**100%**
Salmar Farming AS	0	0	333	343	0	0	2260	30%
Salmar Nord AS	152	114	0	0	0	0	626	42%
Sørrollnesfisk AS	57	0	0	0	0	0	57	**100%**
Stingray Marine Solutions AS	0	0	25	0	0	0	25	**100%**
Wilsgård Fiskeoppdrett AS	57	38	0	0	0	0	95	**100%**

Appendix F – NASDAQ Salmon Index 2005 – 2019

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019*
Consumer Price Index (CPI)	82,30%	84,20%	84,80%	88,00%	89,90%	92,10%	93,30%	93,90%	95,90%	97,90%	100,00%	103,60%	105,50%	108,40%	110,20%
Yearly Average in NOK	20,81	27,01	21,18	22,66	27,49	34,49	29,17	24,60	38,01	39,71	41,45	64,93	63,22	65,01	69,61
Average Week 1 -20 in NOK	19,50	26,36	23,09	22,05	26,97	33,36	37,77	25,12	36,32	45,36	39,84	61,95	69,78	70,38	69,61
Week 15 in NOK	20,35	30,57	24,76	21,60	30,86	37,76	41,47	26,25	40,82	43,63	40,24	58,88	68,01	74,93	73,57

*CPI for January - April; Yearly Average for CW 1 - 20





Appendix G – Salmon Production Costs per kg 2008 – 2017

		2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Smolt Costs per kg	Kr	2,13	1,97	2,45	2,27	2,16	2,19	2,52	2,72	3,18	3,43
Feed Costs per kg	Kr	9,93	9,99	10,98	11,00	10,85	11,50	11,83	13,18	14,55	14,38
Insurance Costs per kg	Kr	0,15	0,14	0,15	0,14	0,12	0,11	0,10	0,13	0,13	0,13
Labor Costs per kg	Kr	1,45	1,30	1,69	1,60	1,55	1,80	1,92	2,07	2,28	2,73
Depreciation per kg	Kr	1,08	1,01	1,16	1,09	1,15	1,23	1,26	1,58	1,80	1,94
Other Costs per kg	Kr	2,93	2,94	3,30	3,36	3,26	5,58	5,54	6,31	8,71	8,13
Net Financing Costs per kg	Kr	0,95	0,39	0,29	0,19	0,22	0,28	0,20	0,16	-0,04	0,02
Production Costs per kg	Kr	**18,61**	**17,73**	**20,03**	**19,66**	**19,31**	**22,69**	**23,38**	**26,15**	**30,60**	**30,74**
Slaughter Costs incl. Shipping per kg	Kr	2,37	2,38	2,84	2,52	2,67	2,64	2,46	2,95	3,26	3,09
Total Costs per kg	Kr	**20,98**	**20,11**	**22,87**	**22,18**	**21,98**	**25,33**	**25,83**	**29,10**	**33,86**	**33,84**

Appendix H – WTP Analysis

Month	Number of fish	Weight per fish (kg)	Total biomass (kg)	Price (NOK/kg)	Cost (NOK/kg)	Profits per rotation	NPV	WTP
1	323,534	0.03	8,611	23.63	22.00	NOK 14,015	NOK 2,795,924	NOK 325
2	317,807	0.10	32,709	24.05	22.00	NOK 66,947	NOK 6,661,234	NOK 204
3	312,182	0.22	69,806	24.70	22.00	NOK 188,344	NOK 12,462,323	NOK 179
4	306,657	0.38	117,560	25.54	22.00	NOK 415,982	NOK 20,591,784	NOK 175
5	301,229	0.58	173,771	26.52	22.00	NOK 785,961	NOK 31,047,113	NOK 179
6	295,897	0.80	236,374	27.61	22.00	NOK 1,325,375	NOK 43,519,797	NOK 184
7	290,660	1.04	303,433	28.75	22.00	NOK 2,047,649	NOK 57,486,402	NOK 189
8	285,515	1.31	373,134	29.91	22.00	NOK 2,950,426	NOK 72,295,271	NOK 194
9	280,461	1.58	443,784	31.05	22.00	NOK 4,015,661	NOK 87,244,129	NOK 197
10	275,497	1.87	513,802	32.14	22.00	NOK 5,211,473	NOK 101,645,432	NOK 198
11	270,621	2.15	581,717	33.17	22.00	NOK 6,495,248	NOK 114,877,568	NOK 197
12	265,831	2.43	646,161	34.10	22.00	NOK 7,817,447	NOK 126,421,138	NOK 196
13	261,126	2.70	705,863	34.93	22.00	NOK 9,125,603	NOK 135,880,517	NOK 193
14	256,504	2.96	759,651	35.65	22.00	NOK 10,368,063	NOK 142,991,636	NOK 188
15	251,964	3.20	806,441	36.26	22.00	NOK 11,497,076	NOK 147,617,654	NOK 183
16	247,504	3.42	845,236	36.75	22.00	NOK 12,470,960	NOK 149,734,655	NOK 177
17	243,123	3.60	875,120	37.15	22.00	NOK 13,255,214	NOK 149,409,964	NOK 171
18	238,820	3.75	895,259	37.44	22.00	NOK 13,822,525	NOK 146,776,006	NOK 164
19	234,593	3.86	904,891	37.64	22.00	NOK 14,151,838	NOK 142,002,812	NOK 157
20	230,440	3.92	903,326	37.75	22.00	NOK 14,226,733	NOK 135,272,497	NOK 150
21	226,362	3.93	889,944	37.77	22.00	NOK 14,033,572	NOK 126,759,055	NOK 142
22	222,355	3.89	864,187	37.69	22.00	NOK 13,559,987	NOK 116,616,887	NOK 135
23	218,419	3.78	825,561	37.50	22.00	NOK 12,794,443	NOK 104,981,394	NOK 127
24	214,553	3.61	773,628	37.16	22.00	NOK 11,727,789	NOK 91,984,930	NOK 119
25	210,756	3.36	708,008	36.63	22.00	NOK 10,357,786	NOK 77,791,262	NOK 110
26	207,025	3.04	628,372	35.84	22.00	NOK 8,697,811	NOK 62,651,536	NOK 100
27	203,361	2.63	534,442	34.71	22.00	NOK 6,790,997	NOK 46,984,559	NOK 88
28	199,762	2.13	425,987	33.11	22.00	NOK 4,731,220	NOK 31,483,998	NOK 74
29	196,226	1.54	302,822	30.89	22.00	NOK 2,692,445	NOK 17,254,884	NOK 57
30	192,753	0.86	164,803	27.87	22.00	NOK 968,016	NOK 5,981,530	NOK 36

Declaration of Authenticity

Herewith I confirm that this thesis is my own work, which was written without unauthorized assistance and that all references used are marked appropriately.

Bergen, 01.06.2019

Place, Date

Signature

Finally, I confirm that this thesis is my own work and no part of it has been previously published elsewhere or submitted as part of any other module assessment. I acknowledge that any errors or omissions are my sole responsibility.

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