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Land based farming of salmon: economic analysis

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LAND BASED FARMING OF SALMON: ECONOMIC ANALYSIS

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Preface

The research is funded by by Møre og Romsdal fylkeskommune – Marint miljøsikrings- og verdiskapingsfond. The research has been a joint project between NTNU Norwegian University of Science and Technology, SNF Centre for Applied Research at NHH and Norsk Sjømatsenter.

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Many busy people deserve great thanks for having shared their time and knowledge for this research. Special thanks to Bjørn Finnøy, Bendik Fyhn Terjesen, Kåre Olav Monstad and Ottar Vartdal. Valuable insights have also been obtained from Ole Gabriel Kverneland, Ørjan Tveiten, Nils Ole Klevjer, Kurt Oterhals and Heidi Kyvik. Thank you. We do hope to have put information and comments to good use.

Ålesund 6th August, 2017

Trond Bjørndal og Amalie Tusvik

Summary

The aim of this report is to investigate the economics of land based aquaculture of salmon and to compare the competitiveness of land based production to the conventional, sea based production model. Two land based scenarios are analysed: full-cycle grow out of harvestable salmon on land and “post smolt”, the production of larger smolts on land before release of the fish for grow-out in sea.

In the first part of the report, background information on the salmon aquaculture industry is presented. This shows that production challenges and biological issues exist in traditional farming of salmon and there is increasing search for alternative ways of salmon production. The study then analyses two such alternatives, using the methodologies NPV, IRR and analysis of cost of production. Using local and national data, the study is designed to investigate and compare farm-gate cost of production in a Norwegian context, aiming to build an understanding about the price firms will need to fetch over time to stay profitable.

The results indicate that full cycle land based salmon farmers in Norway still might rely on a higher price than sea based farmers do. In terms of using land based technology in combination with sea based grow-out, the study found that it is challenging to estimate the net effect of investment in post smolt for a company as a whole. While some indications are given about the potential effect on cost of production, uncertainty remains about the benefits of post smolt – such as the magnitude of relief of lice related issues and costs. Still, the analysis could shed light on some interesting points with respect to production planning using larger smolts, and hopes to make a contribution to the academic discussion in this respect.

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I. INTRODUCTION

The current study has undertaken economic analyses of land based farming of salmon and examined the technology's competitiveness in relation to traditional sea based farming. Here, competitiveness is assessed in terms of cost of production and return on investment. The report aims to investigate whether the development towards land-based farming is viable from an economic point of view – that is, whether investment in land based farming is an efficient use of society's resources.

Two main scenarios are analysed: 1) full production cycle on land and 2) "post smolt" – an extension of the initial land-based smolt phase, keeping fingerlings on land until they reach a significantly larger size than the traditional release of smolts[1]. The two main scenarios are compared to the current production model, which is net-pens in sea and a smolt size of about 80-100 grams. The first scenario should allow for an exploration as to whether new, land-based technologies constitute a challenge to the current production model by providing the opportunity of moving the entire grow-out of salmon to land based facilities. The second scenario considers whether extended use of land based farming of smolts in combination with the natural sea-based advantages enjoyed in the predominant production model has the potential of enhancing competitiveness and offer economic gains to traditional salmon farmers.

In the literature, there are very few economic analyses of land based salmon farming. The reason for this is the dearth of land based salmon production facilities, so that the few analyses that have been undertaken are engineering studies, implying that estimates are highly uncertain. The closest study to this one is probably that of King *et al.* (2016) who conducted a study on Tasmanian salmon farming operations, where the production scenarios include land based Recirculating Aquaculture Systems (RAS) and inshore sea-pen operations with an annual capacity of 6,000 tonnes Head on Gutted (HOG) production. The study concentrates on financial risk. Boulet *et al.* (2010) analysed and compared the economic feasibility of different production approaches, including conventional net-pens, in the context of the operating environment in British Columbia. Liu *et al.* (2016) modelled production facilities of 3,300 tonnes for sea-pens and RAS, respectively. Their data were based on Norwegian salmon farmers' operations in the sea-pen scenario, while the land-based scenario was based on data developed by The Conservation Fund's Freshwater Institute grow-out trials of Atlantic salmon

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[1] An established definition of what exactly qualifies as «post smolt» has – to the best of our knowledge – not been agreed upon among the general public. Biologically, it is a smolt which has undergone smoltification, i.e., salt water adaptation (which can happen at various ages and sizes depending on the aquaculture environment). In this study, the term is used to describe large smolt, although it has been learnt that this is very imprecise.

in RAS. Iversen *et al.* (2013) compared five alternative production approaches in a Norwegian context including sea-pens and a RAS facility with a production of 3,300 tonnes per annum.

While much can be learned from these studies, all are conducted in specific contexts and some were undertaken a couple of years ago. In terms of comparability of the studies, context and location matter, while the developments in technology and operations are rapid and continuous. For this reason, a couple of years of development can have much to say for the findings and results. Another, more recent analysis is that of DNB Markets (2017) which provides an overview of the development in land based salmon aquaculture, including analysis of cost of production and internal rate of return (IRR). The study concentrates on full grow-out of salmon in land based facilities in a national and international context, with the investor community as the primary recipient. The report received substantial attention in the trade press as well as within the industry, illustrating the growing interest in land based aquaculture. For all these reasons, this study is believed to represent a contribution to the literature and should be of interest to the industry.

Published analyses of cost of production based on post smolts appear to be equally or perhaps even more scarce. While many of the cited studies compare alternative production modes, no one combined options such land based farming of post smolts followed by sea based grow-out. However, Berget (2016) analysed the economic outcomes of post smolt production using different sizes of smolts. The current study makes a contribution to the hitherto limited literature on post smolt production by shedding light upon some fundamental points with respect to production planning in traditional versus post smolt production modes.

Salmon aquaculture is predominately carried out in open sea pens along the coast. The farms constitute relatively simple constructions that allow for large production volumes with relatively moderate investments in equipment. However, challenges related to diseases, parasites and the environment have led to nearly a full stop in grants of new sea-based production licenses in Norway (Meld. St. 16 (2014-2015)). In common with other salmon producing regions, the Norwegian industry is experiencing that continued growth is constrained by biological challenges, the availability of sheltered inshore sites and regulatory production restrictions (King, *et. al*, 2016). Thus, despite increasing demand for salmon, the room for industry expansion using the current technology under current regulatory and ecological conditions is constrained. This has led to increasing interest in the development of new technologies and new ways of achieving growth in a promising industry.

Among industry participants and in the press, it has been suggested that both production models to be analysed in this study represent potential ways for the salmon aquaculture industry to expand – without either being granted new production permissions or increases in the maximum total biomass (MTB) permitted in the sea (Holm *et. al*, 2015; Kyst.no, 2017[c]; Ilaks.no, 2015; Nofima, n.d.; Rådgivende biologer, 2016). Such a potential should be of great interest to existing salmon producers as well as for potential new entrants – not to mention consumers who have been facing increasingly high prices. The question is whether the benefits of land-based production models – such as free production permissions, increased control of the production environment, shorter production cycles and possibly improved utilisation of production capacity – will make up for higher investments and costs incurred by the technology in relation to operations, equipment and facilities.

To examine this question, the study will undertake investment and cost analyses. Of central concern is also the handling of risk, given the novelty, data scarcity and technological uncertainty associated with land-based production technology. Over time, it is essential to ensure that the operation can maintain a profitable margin between its cost of production and the price it can fetch for its products. To provide insights about the price needed by each production model to stay financially viable over time, analysis of the cost of production per kg is undertaken. The cost analysis is based on a steady state situation, where the company has achieved a production level with associated cash flows that can be maintained over time. As a result, valuable information can be inferred about the relative cost competitiveness between different production modes. Like any technology, land-based aquaculture farms must be able to provide investors an acceptable return on their capital to establish itself as a viable technology. Together, the two analyses – NPV and cost of production – provide important insights to the estimated profitability of alternative production approaches.

In aquaculture, a number of variables determine profitability, including biological factors, capital investments, operational costs and sales price[2]. Many of the actual outcomes in land based aquaculture rely on the degree of success in creating a healthy environment for the fish to grow and prosper. For the analysis of cost of production and expected present value to be carried out, two important building blocks must be established: an investment plan for a planned facility of a certain capacity and the associated production plan. Biological factors are accounted for to the extent possible, although inevitably with major simplifications and uncertainty associated.

Information from the industry and equipment suppliers provide the basis for making assumptions about investments, production and costs in the land-based salmon farms for a given

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[2] Potential differences between the production modes which may be related to price and marketing is beyond the scope of this study.

production capacity. Data have been collected in cooperation with the salmon farming industry and research institutions. Publicly available data from several sources are also used. The analysis is conducted based on Norwegian conditions and for the most part based on Norwegian data sources. Although the collected data are of international relevance, there is an underlying, more or less explicit focus on the implications for Norwegian producers, industry and policymakers.

The report is organised as follows. Chapter II presents background information about the context of the research and the industry developments which have fueled interest in undertaking this study. Most notably it describes the recent industry developments for salmon aquaculture in Norway, where supply has levelled off, with producers facing substantial production challenges. Chapter III presents the methodology used to undertake the study: net present value (NPV), internal rate of return (IRR), steady state cost analysis and sensitivity analysis. Chapter IV is devoted to economic analyses of full cycle land based operations, while Chapter V considers production of 400-g and 600-g large smolts. In Chapter VI, sea based grow-out of large smolt is analysed, while Chapter VII summarises and discusses the results. Background and some additional data are given in the Appendices.

II. BACKGROUND

This chapter will provide a description of the significance of and developments in global aquaculture with emphasis on salmon (*Salmo salar*) in Norway, the largest producer of farmed salmon. It is shown that sea lice have in practice become the industry's major constraining factor – as well as a driver of the search for new innovations, alternative production modes and technologies that can help mitigate or circumvent the issue. To prevent harm to fish health and sustainability, industry regulations have become more restrictive, with increased emphasis on environmental factors. Irrespective of high demand, new permissions and production increases are limited until the industry demonstrates ability to control and eliminate biological problems (Norwegian Ministry of Trade, Industry and Fisheries, 2016). Consequently, a window of opportunity has opened for new technologies, such as land based farming, to establish itself as a potential way of meeting the increasing demand for salmon.

The chapter is organised as follows. Section 2.1 presents a brief introduction to the state of global aquaculture. The role of salmon in global seafood markets is described briefly in section 2.2, including its widespread acceptance among consumers internationally. Section 2.3 reviews the Norwegian salmon aquaculture industry; a review of the industry's growth and expansion, developments in production cost, environmental challenges, smolt production and a look at the regulatory framework. Notably, challenges and costs related to parasitic sea lice are elaborated upon. Finally, a short review of land-based technology in aquaculture, particularly salmon aquaculture, is given in section 2.4 before briefly summarising in section 2.5.

2.1 Global food supply and aquaculture production

The world's growing population needs more seafood. Global per capita fish consumption rose to more than 20 kg a year for the first time in 2014, according to the most recent edition of The State of World Fisheries and Aquaculture (SOFIA) 2016, a publication by the Food and Agriculture Organisation (FAO, 2016). Given that wild fish stocks are to a large extent fully or even overexploited, growth in fish supply must in principal come from aquaculture (ibid.). As capture fishery production has remained relatively static since the late 1980s, aquaculture has been and will be the source of growth in the supply of fish for human consumption (ibid.).

Whereas aquaculture provided only 7% of fish for human consumption in 1974, the contribution of aquaculture overtook that of wild-caught fish in 2014. The supply of seafood has been growing not only in absolute quantity, but also more rapidly than global population growth, increasing the global per-capita supply (Lem *et. al*, 2015). Indeed, one way of supplying mankind with enough animal protein in the future may be through aquaculture (Lem *et. al*, 2015; Economist, 2016). With awareness of the aquaculture sector's important role in nutrition comes greater responsibility as to how resources are managed to ensure nutritious and healthy diets for a growing population, while managing the impact on the environment. As the sector expands further, it must consider how to improve its environmental impact: this is essential to the long-term economic sustainability of aquaculture as well as to food security (Science for Environment Policy, 2015). Thus, there is a need to explore and seek out the best production models for further expansion of the aquaculture industry. The salmon aquaculture industry provides an example in this regard as is investigated in this study.

2.2 Salmon aquaculture

Salmon farming is among the most successful aquaculture industries with a production growth in recent decades that is higher than aggregate aquaculture production – despite being a high-value product (Asche *et al.* 2013). With respect to quantity consumed, salmon is among the top five species in most major seafood markets (Asche & Bjørndal, *op.cit*). Atlantic salmon, of which nearly all commercially available production is farmed, is a growing part of the global protein supply (Marine Harvest 2016).

From a global supply of farmed salmon of just over 10,000 tonnes in 1981 (ibid.), farmed salmon supply surpassed 2.3 million tonnes in 2015 (figure 2.1). It is considered among the leading species in industrialised aquaculture, accounting for about 7.2% of quantity and 16.6% of value in global seafood trade in 2013 (FAO Fish Stat; FAO 2016).

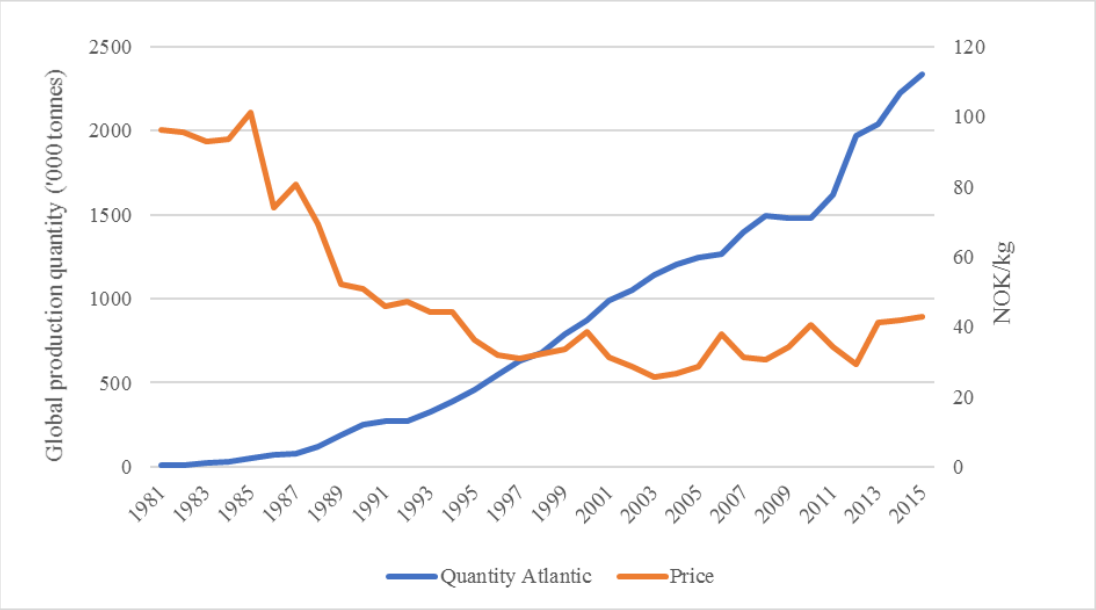

Figure 2.1: Global production quantity in thousand tonnes and real price FOB HOG NOK/kg of Atlantic salmon. 1981-2015.
Source: Kontali, FAO and Statistics Norway.

Figure 2.1 gives the Norwegian export price – free on board (FOB) head on gutted (HOG) as indicative of the world salmon price[3]. As illustrated, after staying at a level around NOK 100/kg, the price started declining after 1985 to NOK 31.90/kg in 1996. During the decade since 2005, increasing demand has maintained world salmon prices in spite of increasing global supply. Although with some fluctuations, prices of farmed salmon have overall remained at levels well above cost of production – as will be shown below. In particular, Norwegian salmon farming companies enjoyed a highly favourable price and currency situation between 2014 and 2016 (FAO, 2016).

Salmon remains a high value, relatively expensive product. The ability to pay makes the EU, Japan and the US the most important markets, and this is where the most significant quantities are consumed. Good logistics and a good reputation have made salmon a species that is consumed across the globe, counting almost 150 countries globally (Asche & Bjørndal *op. cit*). Overall, demand is growing steadily, and new markets are being opened through new types of processed products (FAO, 2016). An important trend in marketing which has helped to maintain price is penetration into new market segments through the distribution of increasingly affordable fresh and frozen products to supermarkets. Increased control over the production process and the predictability of supply achieved in aquaculture production have profoundly changed the ways in which seafood can be marketed and further contributed to the industry's success (ibid). Throughout the value chain, the salmon industry is at the forefront of the seafood industry when it comes to state-of-the-art operating practices (Asche *et al.* 2013). Sophisticated transaction mechanisms and future contracts are used, large processing facilities are established close to major markets and a considerable share of product supply is fresh, the most valuable product form (ibid).

Global megatrends in the food and consumer markets of relevance to the salmon aquaculture industry include increasing awareness towards health and nutrition, sustainability and traceability in food production. Lem *et al.* (2015) identify five important consumer trends and purchase drivers for the period until 2030: food safety and health benefits; social concerns and corporate social responsibility; production systems and innovations; sustainability; food origin and traceability. Potential new entrants such as land based producers have frequently noted these trends, seeing opportunities for product differentiation and added value by e.g. emphasising fully traceable, sustainable and potentially domestically produced salmon.

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[3] This is justified because Norway is the largest salmon producer while HOG is the most important product form.

2.3 Salmon aquaculture in Norway

2.3.1 Norwegian production of farmed salmon

Norway accounted for over half of the world's salmon production in 2014 (Marine Harvest 2016). Atlantic salmon farming in Norway started at an experimental level in the 1960s and became an industry in the 1980s (Asche & Bjørndal, 2011). The total sales quantity[4] of Norwegian farmed salmon increased from 204,000 tonnes in 1994 to 1.3 million tonnes in 2015 (Figure 2.2). While sales quantities grew more than six-fold, employment increased merely 56% over the same period. Industrialisation and specialisation within the industry has allowed for great technological progress and cost reductions in production (Asche *et al.* 2013).

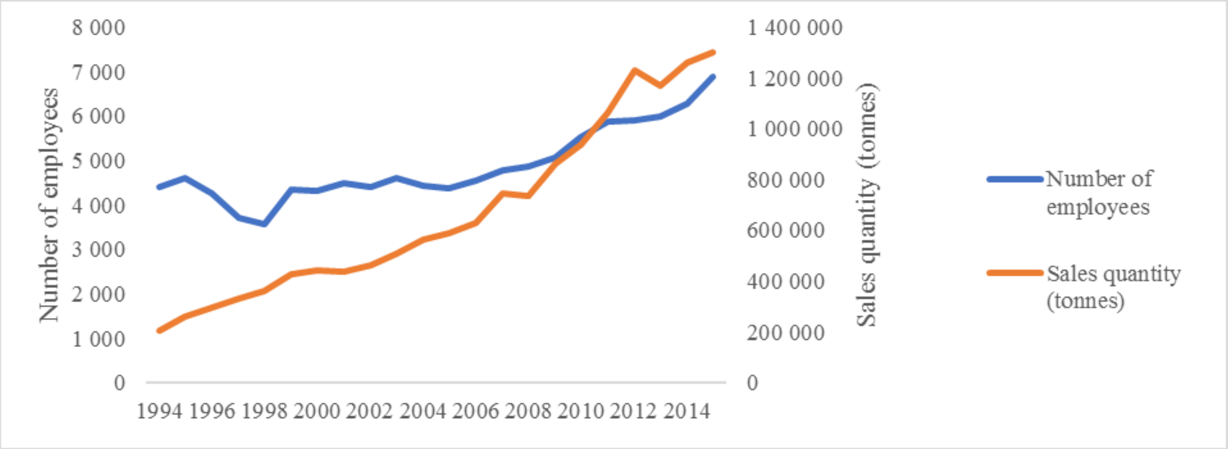

Figure 2.2: Number of employees and total sales quantity (tonnes) in the Norwegian salmon farming industry. 1994-2015.
Source: The Norwegian Directorate of Fisheries

Expansion in production quantity during the past decades can be attributed largely to productivity improvements and increased output per license[5], as the number of licenses has remained rather stable since the end of the 1980s (Asche & Bjørndal, 2011). As illustrated in figure 2.2, sales quantity per license in Norway increased from 252 tonnes in 1994 to 1,338 tonnes in 2015, suggesting a substantial intensification in the industry.

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[4] Sales quantity of salmon is given in whole fish equivalents (WFE). This is the weight measure that will be used throughout this study, also when analysing cost of production per kg. In accordance with NS 9417:2012 and the current practice of the Norwegian Directorate of Fisheries, the conversion factor from live weight to WFE is 1.067.

[5] Originally, the expression license was used for production permissions in Norway (*konsesjon* in Norwegian). Over time, the terminology has changed and the term now used is permission (*løyve* in Norwegian). The terms will be used interchangeably in this report. It is believed that legal rights and obligations are unchanged, although that will not be considered further here.

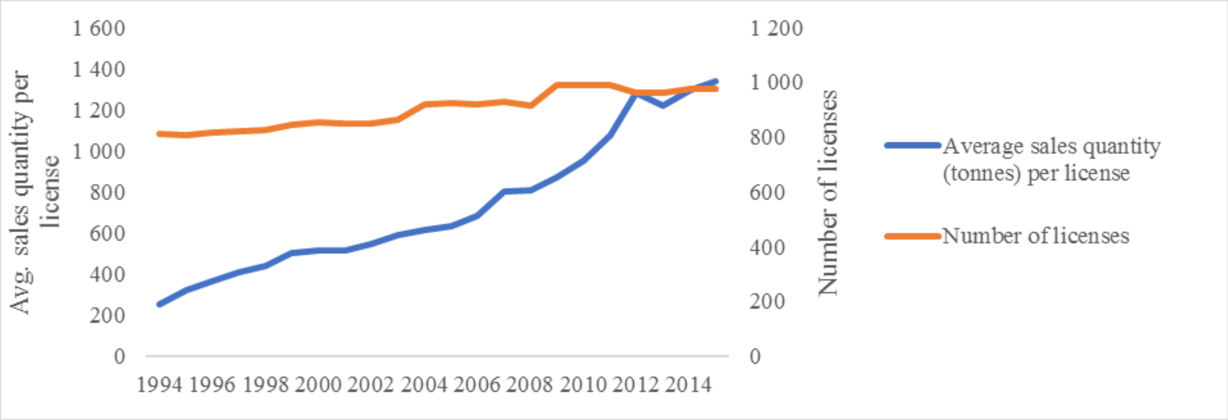

Figure 2.3: Average sales quantity (tonnes) per license and number of licences in Norwegian salmon aquaculture (only salmon). 1994-2015.
Source: The Norwegian Directorate of Fisheries

While an average firm in 1982 had a production of 47 tonnes (Asche *et al.* 2013), this had increased to an average sales quantity per firm of 8 045 tonnes in 2015 (the Norwegian Directorate of fisheries, 2016). It is notable how not only the total production per firm but also the quantity firms are able to produce per permission have increased while firms grew larger and the number of permissions per company increased (see figures 2.3 and 2.4).

Up until 1993, the number of production permissions per firm was set to one by industry regulations. From only one license per company before 1993, the number of licenses per company increased steadily to an average of six to seven licenses per company in 2015. The number of companies in the industry decreased from 467 in 1999 to 162 in 2015 (see figure 2.4[6]).

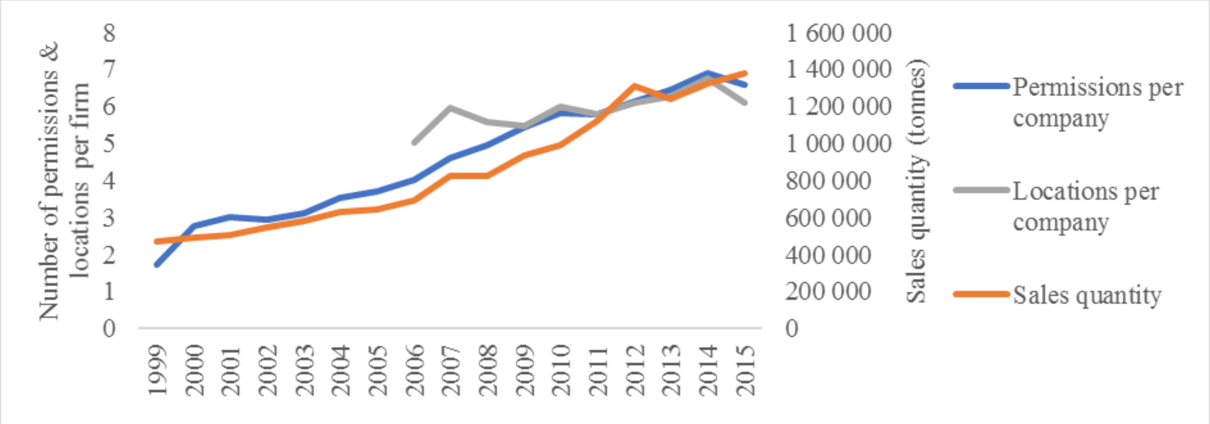

Figure 2.4: The average number of licenses and locations per company and total industry sales quantity (tonnes). 1999-2015. Salmon and trout.
Source: The Norwegian Directorate of Fisheries

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[6] Data on the number of companies has only been acquired from 1999.

A specific feature of the Norwegian production permission system since 2005 is the regulation of standing biomass per license, Maximum Allowable Biomass (MTB). This involves an absolute limit to the biomass a company can have in sea at any time. As a consequence, the output that can be produced is much dependent on the ability to have as continuous a production as possible – with a biomass in sea that is close to the MTB at all times[7]. The license regime is discussed further under section 2.3.5 on the regulation of the Norwegian salmon aquaculture industry and later in chapter VI.

Norway´s position as the world's leading supplier of farmed Atlantic salmon is among other things a result of favourable natural conditions and a relatively simple, low-cost technology (sea pens), exploiting the advantage of free ecosystem services (Iversen *et al.* 2013). Although the open sea pen technology has been cost efficient and offered substantial growth over the past decades, concerns are mounting about production challenges and the industry’s environmental footprint. In the following sections, much of the discussion evolves around the issue of sea lice and associated production challenges. To examine the situation and developments over time, attention is devoted to production costs, environmental issues and the regulatory framework.

2.3.2 Developments in productivity and production cost

As noted, Norwegian salmon production has increased significantly during the previous decade. At the same time, production costs declined substantially as shown in figure 2.5, giving average cost of production per kg for 1985-2015 (measured in real 1999 NOK). Reduced production costs over the industry’s first decades were primarily due to two factors (Asche & Bjørndal, 2011). First, farmers became more efficient, as they produced more salmon with the same quantity of inputs. i.e., productivity growth. Second, improved input factors (e.g. better feed and improved feeding technology) made the production process less costly through lower prices

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[7] In turn, this might have contributed to the development in companies’ ability to extract increasing quantities per permission as the average company size and number of permissions and locations per firm increased – even as the MTB per license and number of licenses remained relatively flat. Nevertheless, although production quantities per license have increased while companies have become larger over time, explanations for this could also include technological progress, learning, specialisation of the industry and other effects. Not only in Norway, but in all of the five leading salmon producing countries, the degree of concentration has increased and firms have become larger over time (Asche *et al.* 2013).

for inputs and lower quantities of inputs used per unit of output (ibid). Among other factors explaining the reduction in production cost, economies of scale is perhaps the most important[8].

In real terms, the cost of production per kg was reduced from NOK 77.90 in 1986 to NOK 16.80 in 2005 (figure 2.5). Over the same period, the profit margin[9] has been positive for most of the time but with some exceptions[10]. It can be observed that price has been declining in line with cost of production, implying that cost savings have been passed on to consumers through price reductions (Asche & Bjørndal, op.cit).

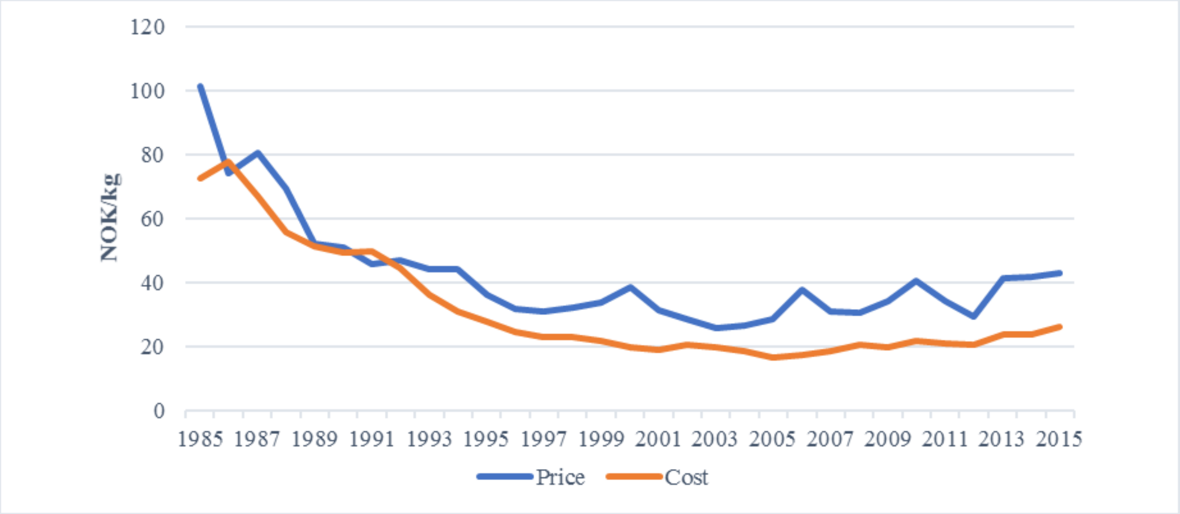

Figure 2.5: Price and real production cost in NOK per kilogram. 1985-2015.
Deflated by the Consumer Price Index with 1999 = 100.
Source: FAO, Kontali and Statistics Norway.

However, concerns are now being raised that the trend of positive productivity growth and decreasing production costs has come to an end. The average cost of production per kg across the Norwegian salmon grow-out producers reached a bottom at NOK 16.80 in 2005. By 2015 it had increased to NOK 26.15 per kg, an increase in real price of 55.7% over 10 years or almost a doubling in nominal terms (see table 2.1).

Table 2.1 shows the distribution of nominal production cost per kg among cost categories for the years 2005 and 2015 and their respective changes over the period. Apart from insurance and financial costs, which both declined notably over the period (but are small in

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[8] Systematic breeding, improved pharmaceuticals, disease control and feed quality were other contributing factors to the declining costs.

[9] The price in the figure is export price while costs do not include e.g. transportation. Therefore, the difference between price and cost may exaggerate the profit margin. Nevertheless, the figure clearly shows the trend over time.

[10] It is noted that in particular in the years 1989-91 this margin was very small or negative. Presumably, the price was more or less the same for all producers while there was great variation in cost (the figure represents average cost for farmers). Accordingly, in these years many faced economic difficulties and a large number went bankrupt. In turn, this caused a change in ownership regulations as will be discussed below in section 2.3.4.

absolute terms), other cost components increased. Increases in feed costs and other operating costs constitute by far the most prominent parts of the increase, amounting to NOK 10.51 out of the total increase of NOK 12.35: Feed costs increased by 77%, while other operating costs increased by 315%. Together, the two cost components represented 74.5% of total production costs in 2015. Other components such as smolt cost, wages and depreciation also increased in nominal terms.

Table 2.1: Nominal production cost by category in NOK per kilogram. Cost shares in percent of total production cost per kilogram. 2005 and 2015.

	2005	**2015**	**Change**
Smolt cost	1,85 13 %	2,72 10 %	+ 0.87 (+47%)
Feed cost	7,46 54 %	13,18 50 %	+ 5.72 (+77%)
Insurance	0,22 2 %	0,13 0 %	- 0.09 (-41%)
Wages	1,38 10 %	2,07 8 %	+ 0.69 (+50%)
Depreciation	0,83 6 %	1,58 6 %	+ 0.75 (+90%)
Other operating Costs	1,52 11 %	6,31 24 %	+4.79 (+315%)
Financial cost	0,55 4 %	0,16 1 %	- 0.39 (-71%)
PRODUCTION COST	**13,80** 100%	**26,15** 100%	**+12.35 (+89.5%)**

Source: The Norwegian Directorate of Fisheries.

The large impact of rising feed costs stems from its considerable share of the total production cost. Meanwhile, its share of the total changed relatively little, in fact declining from 54% in 2005 to 50% in 2015. Reasons for the increase in feed costs (apart from general inflation) may include more expensive marine raw ingredients, increased use of specialty feed for growth, fish health or medicinal purposes and a weakened Norwegian currency in the most recent years (Iversen *et al*, 2015).

Other operating costs have risen sharply, more than trebling since 2005 in nominal terms. At the same time, its share of total production costs rose from 11% in 2005 to 24% in 2015. Costs that are accounted for by this category include costs related to fish health, as well as maintenance, electricity, rents, office costs, reparations, etc. (The Norwegian Directorate of Fisheries). Importantly, the cost category thus includes the increasing costs related to sea lice (a parasite), including fish health and mortality, prevention, treatments, medication, compliance and reporting. Indeed, most of the increase in other operating costs are in various ways associated with sea lice (Iversen *et al*, 2015). In this respect, it is also worthwhile to note another possible effect on the changes in cost of production per kg, which is related to the measure itself. Among the consequences of sea lice infection is that the average harvest weight has decreased. According to one industry representative, the average harvest weight decreased by 0.5 kg between 2010 and 2016, when the sea lice related problems also took off (Ilaks.no, 2017). In turn, lower average harvest weight might increase cost of production per kg.

With regards to capital costs, it is important to note that the statistics do not take the value of production licences or permissions into account. Thus, capital costs in the statistics consist primarily of depreciation on operational equipment such as net pens, floats and vessels, feeding systems and monitoring equipment, etc., amounting to 6% of production cost per kg in 2015. Considering the cost component financial cost, this probably consists mainly of interest on mortgages and lines of credit. These are the actual financial costs incurred by firms. If the equity is large, such financial costs are likely to be low.

This implies that the firms' most valuable assets – namely production licences – are largely left unaccounted for except for instances where firms have taken over other firms[11]. For a firm to establish a sea-based salmon grow-out farm, both locations and production permissions are required. The value of a license is challenging to estimate, as transactions rarely happen in Norway. As discussed in more detail below, the last issue of new licenses in 2013 saw a total of 15 licenses to be auctioned and sold at prices ranging between NOK 55 and 66 million (Hjelt, 2016; EY 2017). Since then, the price of salmon has increased considerably (as shown in figure 2.1).

DNB (2017) estimated investments in sea based licenses to range from NOK 60-120 million per license in 2017, making up the majority of the total farm investmen. Investment in farm equipment were estimated to about NOK 15/kg by DNB, while investments in licenses would amount to NOK 45-90/kg under the assumptions of 1,338 tonnes of production per license and a price of NOK 60-120 per license[12]. While the market price of a license might be up to 120 million according to DNB Markets (2017), the Norwegian Minister of Fisheries recently indicated values of up to 100 million in 2017[13]. Marine Harvest (2016) estimated the market price of a license to be between € 4.5 and 7 million. Hence, exclusion of this component

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[11] In recent years, there have hardly been any sales of licenses. Thus, where license values are included in firms' assets, values are much less than today as they are based on historical acquisition values.

[12] As noted previously, the average production per license in Norway was 1,338 tonnes in 2015.

[13] Vestlandskonferansen, a conference, March 30, 2017 in Stavanger, Norway.

may lead to a seriously misleading picture of the actual capital costs. As shown above, the average company in 2015 operated six licenses. At market prices, the investment in licenses required to establish salmon aquaculture operations are quite substantial.

It follows from this that the official statistics can be misleading with respect to the actual capital cost in salmon aquaculture. Given a license value of NOK 80 million and a real interest rate at 4%, we are talking about an interest charge of NOK 3.2 million per license per year or NOK 2.39/kg. Should the license value be NOK 120 million, the interest charge would become NOK 3.59/kg. Whatever assumptions are made about license value and interest rate, the opportunity cost is fairly substantial, indicating that official statistics underestimate the true cost of producing farmed salmon.

The next section will discuss further the environmental issues and production challenges in salmon aquaculture, particularly sea lice.

2.3.3 Environmental issues and production challenges in salmon aquaculture

Any production process that interacts with the natural environment has the potential to damage the environment around the production site (Asche & Bjørndal, op. cit). For salmon farming, the main issues have been pollution from organic waste and the interaction between wild and farmed salmon. Farmed salmon may transmit diseases to wild salmon, and escaped farmed salmon may attempt to spawn in rivers and thereby impact the genetic pool for wild salmon (ibid.). Although sea-based aquaculture production of salmon provides good growth under normal conditions and is believed to be a sustainable and efficient way of producing proteins for human consumption, challenges do exist. Some major environmental concerns are attributed to emissions due to organic waste, the use of chemicals and antibiotics, escapees and sea lice. This section will focus on challenges related to sea lice. For a brief review of the historical development in escapees, feed use (FCR) and antibiotics, see appendix, note A1.

In Norwegian salmon aquaculture, the challenges attributed to sea lice (*Lepeophtheirus salmonis*), a parasite, currently (2017) stands perhaps as the single most important challenge to the industry (Hjeltnes *et al.* 2017). In its adult life stage, sea lice attach to the body of their host, feeding on their skin and underlying tissue (ibid.). Primary host responses include reduced appetite and growth, external wounds, increased stress and reduced vitality due to susceptibility to infections and disease (Abolofia *et al.* 2017). Aquaculture farms provide conditions which may allow parasites and diseases to flourish more easily; farmed fish are usually stocked at a higher density than wild fish, providing parasites, bacteria and infections the opportunity to accumulate and multiply (Science for Environmental Policy, 2015). Sea lice are believed to spread at a seaway distance of 20 km, perhaps even more in areas close to land and with good currents, and are increasingly observed on other species – including wild salmon (Morency-Lavoie, 2016). Spatial externalities and locational interdependencies complicate effective eradication, with problems in one area influencing returns in other nearby locations (ibid.). Costs and concerns related to sea lice constitute a main driver towards closed or offshore farming systems (along with market conditions: salmon demand, supply and price).

Means of sea lice treatment and prevention include biological means: the use of wrasses (cleaner fish); medical treatments, including in-feed pellets (oral); chemical treatments, including bath delousing (hydrogen peroxide) and mechanical treatments (Morency-Lavoie, 2016). In addition, numerous innovations in equipment and production modes are turning up in response to the challenges facing the industry, where examples include fully-enclosed pens, "snorkel" barriers, tarpaulin shielding skirts, open-ocean facilities and land-based facilities (ibid.).

Abolofia *et al.* (2017) estimate, over an 84-month period from January 2005 through December 2011, that an average lice infestation over a typical spring-release cycle in the Norwegian central region generates damages of $0.46 per kg of harvested biomass, equivalent to 9% of farm revenues. Yet in parts of Norway, it may be as high as 13% of revenues (ibid.). According to Morency-Lavoie (2016), the cost of lice treatments increased five-fold from 2011 to 2016, with treatments alone amounting to NOK 5/kg or about 20% of production cost. Excluding effects of reduced growth, higher feed conversion ratio, mortality and deterioration in the product quality, Iversen et al. (2015) estimated industry-wide annual lice treatment costs of up to NOK 5 billion, probably ranging from 3-4 billion in 2014. DNB Markets (2017) estimate that given recent developments, the cost of sea lice should add up to at least NOK 5/kg in Norwegian cost of production in 2016-17. This is consistent with the view of Morency-Lavoie, op.cit. According to Hjeltnes *et al.* (2017), lice treatment costs have now passed NOK 5 billion per year.

And yet, the real cost of sea lice extends beyond the direct treatment costs. In a review of other existing literature on the subject, Abolofia *et al.* report the findings of Mustafa *et al.* (2001), who found through qualitative studies of Canadian salmon farms that the greatest loss due to sea lice was attributable to reduced fish growth – at 200 grams per fish per cycle. Similarly, Rae (2002) found that the costs of stress and losses due to reduced growth of infected fish were approximately 5% of the annual production value at Scottish farms. Costello (2009) estimated the global cost of sea lice control to $ 480 million in 2006, corresponding to 6% of the total annual production value of farmed salmon in the affected countries. The most significant costs of sea lice were treatment costs, reduced fish growth and reduced food conversion efficiency. More intangible effects such as the industry's image and reputation comes in addition.

While antibiotic treatments are very limited and nearly non-existent from a historical perspective (see appendix, figure A3), the use of chemicals and other means for treatment of sea lice is on the rise. The same is true for a more environmentally friendly method of treating sea lice, namely the use of "cleaner fish" or wrasses. These have been introduced to net pens because they feed on sea lice (Asche & Bjørndal, op. cit). Figure 2.6 shows the use of "cleaner fish" for lice treatment and prevention in Norwegian salmon farms. As illustrated, the use of cleaner fish has increased considerably over the past decade, both in absolute quantity and relative to total salmon production and sales. From about 4.9 million fish in 2009, the quantity of cleaner fish exceeded 26.4 million in 2015. On its own, however, this measure has not been sufficient to eliminate sea lice (ibid.).

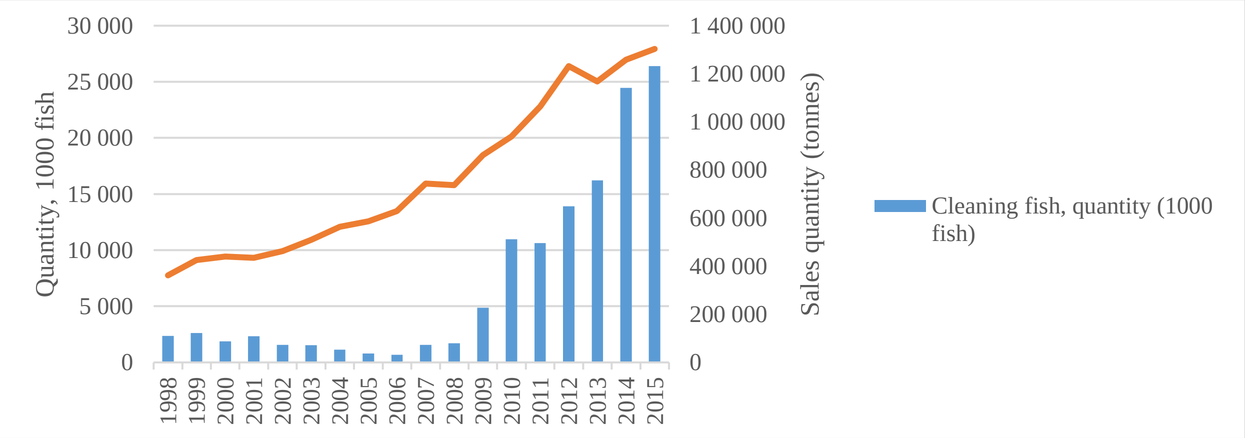

Figure 2.6: The use of wrasses or "cleaner fish" for lice treatment and prevention in Norwegian salmon farms (quantity, 1000 fish) compared to total Norwegian sales of farmed salmon (tonnes). 1998-2015.
Source: The Norwegian Directorate of Fisheries

Figure 2.7 illustrates the use of medical parasitic agents in Norwegian salmon aquaculture. The use of ectoparasitic agents is mainly against salmon lice, and can be used for treatments via feed or for immersion (Gustavson *et. al*, 2009). The increase in its use has been explosive, both in absolute quantity and relative to production. From a quantity of about one ton in 2008, the use of endo and ectoparasitic agents exceeded 15.4 tonnes in 2015.

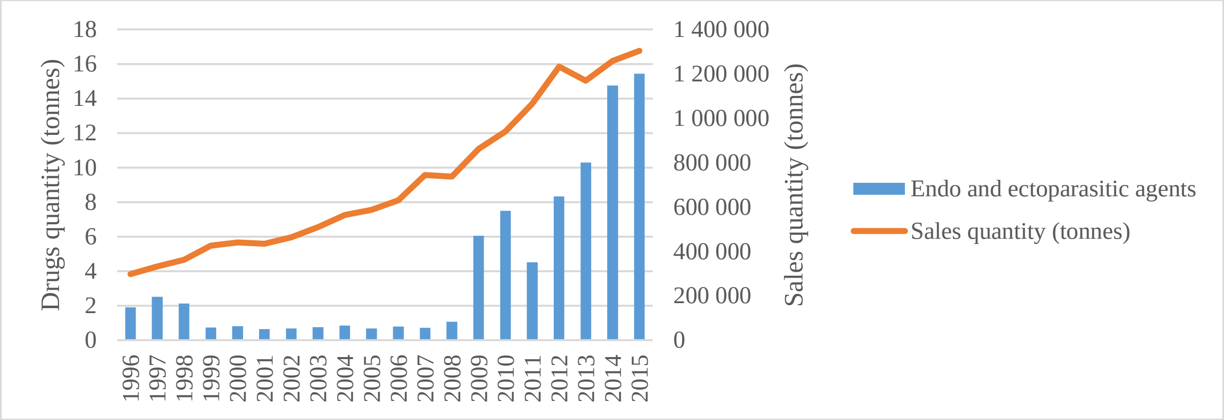

Figure 2.7: The use of endo and ectoparasitic agents in Norwegian salmon aquaculture in quantity (tonnes) compared to total Norwegian sales of farmed salmon (tonnes). 1996-2015. *Source:* Norwegian Institute of Public Health.

Another chemical used in the treatment of sea lice is hydrogen peroxide. Reliance on medical delousing resulted in widespread resistance amongst salmon lice. In attempt to combat resistant salmon lice, hydrogen peroxide (H_2O_2) became increasingly used in salmon immersion (lice bath) treatments (Helgesen *et. al*, 2017). Its use increased tremendously in absolute as well as in relative quantity, starting from 2009. From a quantity of 308 tonnes in 2009 (zero in 2008), the use of hydrogen peroxide exceeded 43 thousand tonnes in 2015.

Problems related to resistance reached new levels in 2016, with observations of accidents under treatments and lice related fish damages at many sites (Hjeltnes *et al.* 2017). In the same year, the number of medical treatments declined by 41%, while the number of mechanical treatments increased six-fold (ibid.). An important explanation for the repeated change in treatment form is the development of resistance against the medical and chemical treatments used (ibid.). Meanwhile, reported incidences of substantial mortalities following lice treatments are substantially higher for mechanical than medical lice treatments (93% versus 65% of respondents, respectively) (ibid.).

In 2016, 1,122 salmon and trout permissions in Norway[14] were distributed over 566 active locations with a total number of mechanical and medical lice treatments of 3,662, or on average 6.5 per location. In addition, 2702 locations released cleaner fish into net-pens. Whether the entire location or only part of it is treated may vary on a case by case basis. It should be kept in mind that the incidence of lice varies from year to year and it also varies along the coast. In 2016, two counties in Western Norway (Hordaland and Sogn and Fjordane) and Middle Norway (Nord- and Sør Trøndelag) were relatively most affected. It is also noticeable

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[14] Source: The Norwegian Directorate of Fisheries.

that the two northernmost counties, Finnmark and Troms and Nordland, are much less affected, presumably due to lower water temperatures.

While data on lice treatments are presented mostly for Norway, salmon lice are a substantial concern in all salmon producing countries (Abolofia *et al.* 2017).

2.3.4 Smolt Production

Smolts are essential inputs to salmon aquaculture (Sandvold & Tveterås, 2014)[15]. In terms of costs, smolt is the most important input factor in salmon farming after feed and is also considered a major determinant of loss and mortality throughout the life cycle (Sandvold & Tveterås 2014; State Secretary Roy Angelvik[16]). Figure 2.8 provides an overview of important developments in smolt production quantity and real cost of production during the period 1988–2010. From a quantity of 57 million smolts in 1988, Norwegian hatcheries produced 280 million in 2010 (nearly 333 million smolts in 2015). The increased production over time has been accompanied by a substantial reduction in the unit production cost and real sales price. In 1988, the real production costs were around NOK 16 per unit, while in 2005 it reached its lowest reported level at less than NOK 6 before levelling off[17].

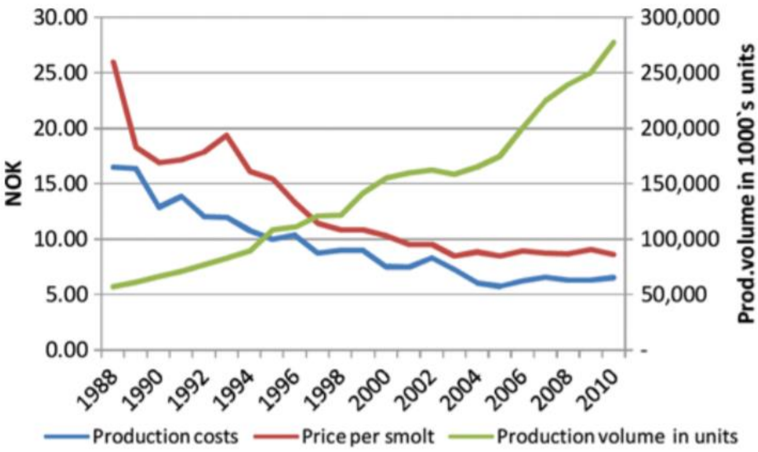

Figure 2.8: Total production of smolt and the associated prices and costs in the Norwegian salmon industry in the period of 1988–2010. Data from the Norwegian Directorate of Fisheries (1988–2010).
Source: Sandvold, H.N. & Tveterås, R. (2014).

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[15] Juvenile production is land based fresh water farming, and includes production of both fry and smolt. The fish is called fry from its hatched at the age of 4-6 weeks and until it reaches the smoltification stage at the age of 8-14 months. Fry is sold to other hatcheries for further growth in fresh water. Smolt is sold to grow-out farms for further growth in salt water. Hence, smolt is the main product of interest for the hatcheries.

[16] Presentation at «Smolt production of the future», a conference, Sunndalsøra, Norway, October 25th, 2016.

[17] For a break-down of nominal production cost, see Appendix, table A1.

The real sales price per smolt also experienced a clear downward trend during the industry's first decades, contributing to lower cost of production for the grow-out plants. In 1988, the sales price was around NOK 26 per unit, while by 2010 it had decreased to NOK 9. Like for the salmon grow-out farms, there is a close relationship between the trend in production cost and price, indicating a competitive industry (Sandvold & Tveterås, 2014). Looking at the more recent years (i.e., including some years after 2010), cost of production has been rising in nominal terms, while operating margins seem to have been under pressure (figure 2.9)[18].

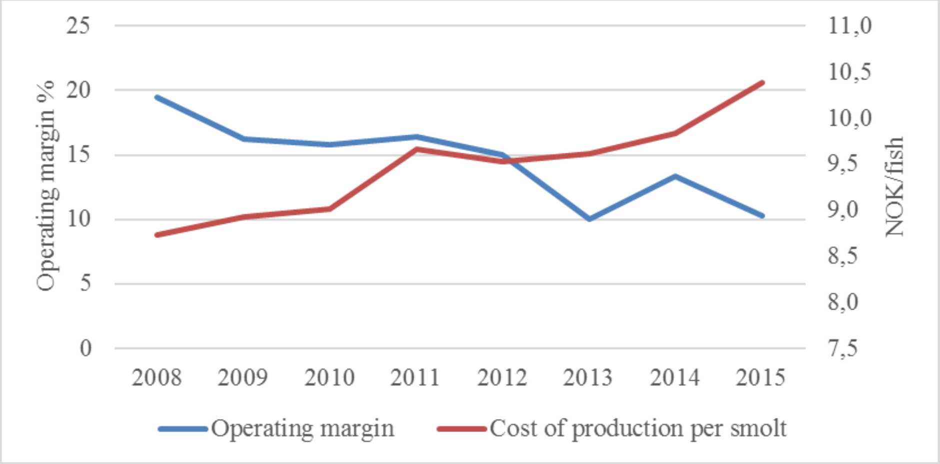

Figure 2.9: Development in average cost of production per smolt and average operating margin in Norway. 2008-2015. NOK (nominal) and margin %.
Source: The Norwegian Directorate of fisheries

Another trend in the same period has been increasing investments (figure 2.10). It may be noted that since 2011, restrictions in terms of production capacity in number of smolts were abolished. Instead, the capacity is now limited by restrictions on water consumption (set by NVE, the Norwegian Water Resources and Energy Directorate) and restrictions on waste quantity (set by the chancellor). A former restriction stating the maximum permitted smolt weight was also abolished in 2016 (The Norwegian Government 2015^b; 2016).

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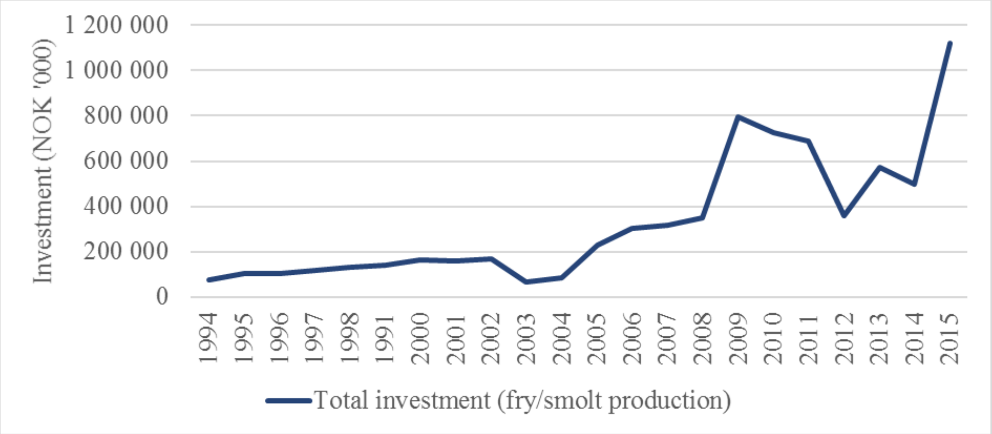
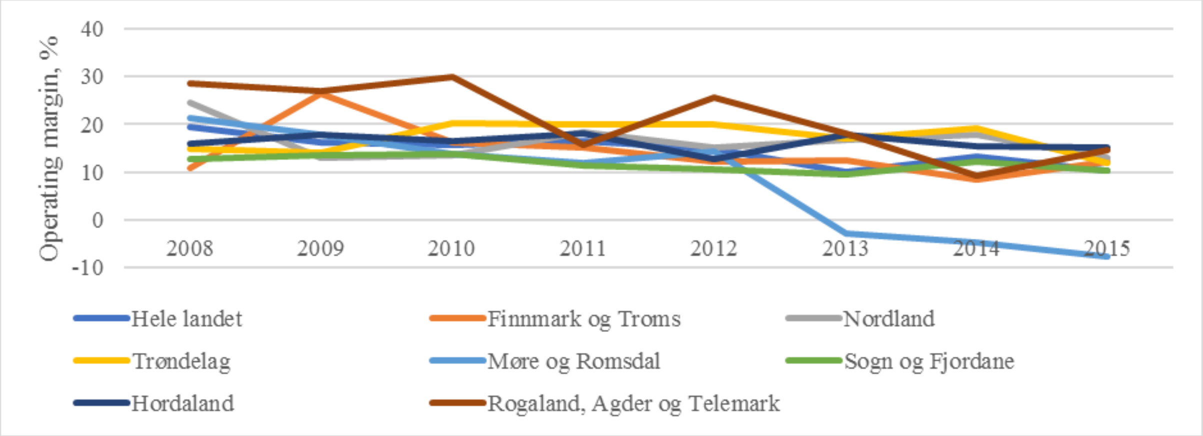
[18] For the development and composition of cost of production per smolt in Norway, see appendix, tables A1 and A2. When it comes to possible changes in the product sold – such as for instance smolt size – this is not discernable from the statistics.



<u>Figure 2.10: Development in investments in the Norwegian salmon smolt and fry industry. Nominal NOK, 1994-2015.</u>
Source: The Norwegian Directorate of fisheries

From industry statistics, only average figures are available on cost of production and prices. However, in terms of operating margin it is possible to look a bit more into variations within the industry. It can be noted that although the performance in operating margins seem to have been converging lately, they are not uniform across the Norwegian industry – although this may very well be explained by prices as well as costs[19]. Nevertheless, apart from the county of Møre and Romsdal which showed a terrible development in average operating margins over the three years from 2013-15, average operating margins varied between 10.3-15.2% among geographical regions (Table 2.2; figure 2.11). Compared to the historical variation, that range is rather narrow.



<u>Figure 2.11: Average operating margin for Norwegian smolt producing firms. Average numbers per county and for the industry as a whole. Operating margin in percent, 2008-2015.</u>
Source: The Norwegian Directorate of Fisheries

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[19] Equivalent statistics on price and cost between regions have not been obtained. Moreover, the differences might be just as large within regions as between.

Table 2.2: Average operating margin for Norwegian smolt producing firms. Average numbers per county and for the industry as a whole. Operating margin in percent, 2008-2015.

Operating margin	2008	2009	2010	2011	2012	2013	2014	2015
Norwegian industry average	19,5	16,2	15,8	16,4	15,0	10,0	13,3	10,3
Finnmark & Troms	10,9	26,4	16,2	15,2	12,3	12,6	8,4	12,2
Nordland	24,6	13,0	13,5	18,4	15,1	16,6	17,9	13,0
Trøndelag	15,0	14,0	20,3	19,9	20,1	17,1	19,2	11,9
Møre & Romsdal	21,2	17,8	13,7	12,0	14,3	-2,8	-4,8	-7,5
Sogn & Fjordane	12,6	13,6	13,9	11,5	10,5	9,4	12,1	10,3
Hordaland	15,9	17,7	16,4	18,0	12,8	17,9	15,4	15,2
Rogaland, Agder and Telemark	28,6	26,9	29,8	15,6	25,5	18,0	9,2	14,5

Over the years, plant size in smolt production has increased. Figure 2.9 shows the development in the number of fish released compared to the number of companies and permissions from 1994-2015. While the industry's output increased considerably – here represented by the release of smolt to sea – the number of smolt producing companies decreased. Thus, an intensification of the industry has taken place also in the case of smolt production.

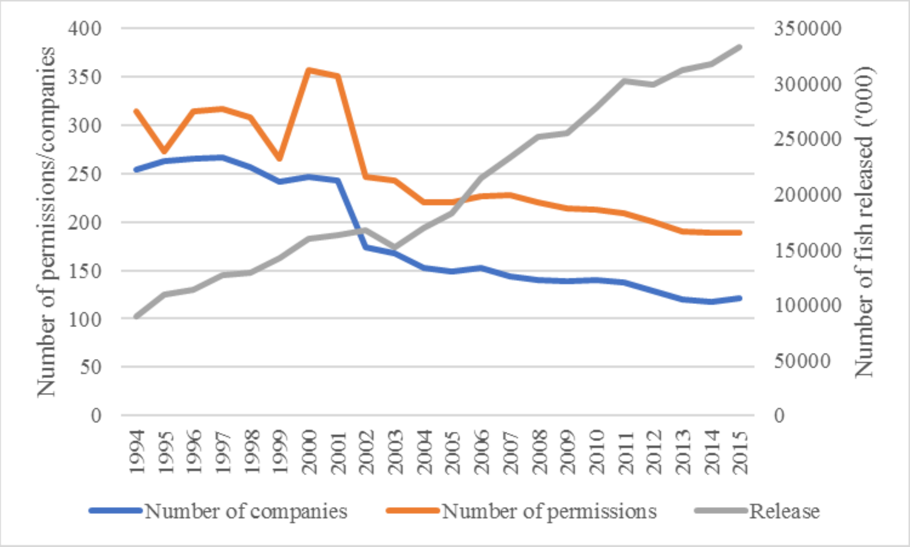

Figure 2.12: The number of companies, permissions and release of fish in Norwegian salmon and trout aquaculture production. 1994-2015.
Source: The Norwegian Directorate of fisheries

In terms of production restrictions, the smolt production permissions vary substantially in size (Sandvold & Tveterås, 2014). Originally, the licenses were given in terms of the maximum number of smolts to be produced each year, but recently one has been moving towards a system that more explicitly addresses environmental issues (ibid.). With respect to former restrictions, concerns were raised that certain regulation could have the unintended consequence of limiting innovation, flexibility and development of new production models

(Asche *et al.* 2014). As such, new licenses are issued in terms of maximum withdrawal of freshwater and maximum discharge of wastewater.

In juvenile production, the technology has changed rapidly over the past decades – with improvements in breeding, fish health, feed and equipment (Sandvold & Tveterås, 2014). Many of the largest innovations in salmon farming have first taken place in smolt production, for example artificial light, water purification system and vaccines. Improved fish health through vaccination has been among the most important measures to prevent spread of diseases.

Production technology and production practices vary between plants, and the industry is more heterogeneous than in earlier years (Sandvold & Tveterås, 2014). In the 1970s, the technology was more or less similar for all plants (ibid.). All the hatcheries operated "flow-through-systems" with no reuse of inlet water and little cleaning of the outlet water (ibid). Recirculation Aquaculture Systems (RAS) technology, which is a closed containment water purification technology with drastically lower water consumption, was first introduced in Norway in 2006 and is now used by many of the new plants (ibid.). Together with regulatory changes, water recirculation has opened new opportunities for land based production of larger smolts. As noted, a long held maximum limit on smolt size of 250 grams has been eliminated, following the introduction of a new regulation of land-based aquaculture (starting from June 1st, 2016)[20].

Introduction of RAS and water purification systems may also contribute towards a more environmental sustainable production (Sandvold & Tveterås, 2014). New hatcheries today have close to zero escapes, low water consumption and effective cleaning of the outlet-water. Improved control over the production process reduce risk when it comes to accidents, escapees and diseases and can potentially offer a higher degree of flexibility and utilisation of capacity for both the land based smolt production and the grow-out farms (ibid.).

2.3.5 Regulation of the salmon aquaculture industry in Norway

All salmon producing countries regulate their industries. Regulations are focused on ensuring that environmental standards are met and coastlines appropriately protected (Asche & Bjørndal, *op.cit,* 34). All countries require an environmental impact assessment, although specific standards differ. As the regulatory requirements vary, so does industry structure and competitiveness (ibid).

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[20] From 2012 and up until then, smolts exceeding 250 g could only be produced with a special exemption from the Norwegian Fisheries Directorate, with application procedures required.

Production licenses are the most important tool used in controlling the production capacity in the Norwegian industry (Asche *et al.* 2014). The salmon industry in Norway has been regulated since salmon farming became commercialised, and the first set of regulations was introduced in 1973 (Asche & Bjørndal, *op.cit,* 34). Operating as a preliminary law, it registered the number of firms (licences) that operated in the country, as well as the production per firm (licence) (Stikholmen, 2010; Bjørndal, 1987). In the beginning, the permission system was very liberal and functioned more in terms of a registry. Up until 1977 almost all applications were permitted (Bjørndal, 1987). For a short look at some historical developments in regulations and the associated changes to industry structure, see appendix, note A2.

In 2005, today's maximum total biomass (MTB) regulation was introduced (Asche & Bjørndal, *op.cit*). As indicated by the name, the MTB sets the maximum biomass allowed in sea per permission at any time. Initially, it was set to 780 tonnes[21] per permission (ibid) and this quota remains the same today. The MTB system operates at two levels: the company level, where the maximum biomass is determined by the company's number of permissions (at a quantity of 780 tonnes per permission) and at the level of a location. The latter is determined at an individual basis with respect to the location's ecological and environmental capacity. Chapter VI will revert to the discussion about the MTB regulation system in a more practical approach to consider its implications on production planning.

During most of the Norwegian salmon industry's history, licenses have been awarded for free, although often with substantial regional policy considerations (Asche & Bjørndal, *op.cit,* 35). However, in 2002 the government introduced a fee of NOK 5 million per license(except for the most northern county, Finnmark, where the fee was NOK 4 million). In 2008, the fee was increased to NOK 8 million (NOK 5 million for Finnmark) (ibid.). Limits on the maximum share of total production licenses that can be owned by a single firm existed up until 2015 to prevent too much concentration. Until November 2015, an industry player had to apply for approval from the Government to be in control of more than 15% of the total permitted biomass in Norway[22]. The regulations were deemed in conflict with the European Economic Area (EEA) agreement by the European Free Trade Association (EFTA) court in 2010 (EFTA 2012)[23]. As a consequence, the regulation of ownership was proposed removed in September 2014, a decision first implemented in November 2015. Requirements about product processing

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[21] Except for a preferential treatment of the two northern counties Troms and Finnmark, with a maximum allowed biomass of 945 tonnes per licence (The Norwegian Directorate of Fisheries, 2016).

[22] Such approval could be given if specific terms regarding the applicants R&D-activity, fish processing and apprenticeships in coastal regions were upheld (Marine Harvest, 2016).

[23] Following complaints from Marine Harvest, the largest salmon aquaculture firm.

with increasing license ownership concentration were also abolished in the same year (Intrafish, 2017a). However, it still applies that no industrial player can control more than 50% of the total biomass in any of the regions of the Directorate of Fisheries (Marine Harvest, *op. cit*).

As of today (2017), the main objective of the regulation is to ensure environmental sustainability (e.g. Asche *et al.* 2014, The Norwegian Government, 2017). Yet, the criteria for granting new permissions have been varying from one round of license grants to another – including considerations such as fish processing, lice count, company structure and production technologies. New permissions have been awarded with uneven and unforeseen intervals, making the growth in production capacity uncertain and unpredictable (ibid). Since 2002, all allocation rounds have upheld various preferences with respect to the organisation of the industry – including policy criteria related to processing, company structure, research and development and the technology applied in production (Asche *et al.* 2014). For instance, a recent allocation in 2013-14 involved both an open auction of permissions (with licenses to be granted to the highest bids) as well as a number of permissions reserved for companies which fulfilled certain policy criteria (ibid). The group of companies which fulfilled the relevant criteria were granted permissions at a price of NOK 10 million. Meanwhile, among ordinary bidders in the same round (not conforming to any criteria), 15 licenses were traded with prices ranging from NOK 55 million to 66 million (with the highest bid not to be granted any license at NOK 55 million) (ibid.).

Sea lice infection on salmon farms has been regulated since 1997 to reduce the harmful effects of lice on farmed and wild fish (Abolofia *et al.*, 2017). Regulations set thresholds for the maximum mean number of sea lice per fish (lice count) and a compulsory reporting system is operated. From 2000 to 2013 the legal lice infection thresholds, enforced by the Norwegian Food Safety Authority (NFSA), was set to 0.5 adult female lice per fish or three lice per fish of other mobile stages (i.e., adult males or pre-adult mobiles) in the period Jan. 1st – Aug. 31st; and one adult female or five other mobile ones per fish in the period Sep. 1st – Dec. 31st (ibid.). If thresholds are exceeded it is mandatory for the farmer to medically treat or slaughter their fish within 2 weeks (ibid.).

Recently, a new growth system to be implemented October 1st, 2017 has been presented for the Norwegian salmon aquaculture industry (The Norwegian Government, 2017). The intention is to ensure sustainable growth of the industry, with future growth to be granted based on sustainability indicators, currently sea lice (Marine Harvest, 2016). Labelled as the "traffic light system", the regulatory system divides the country into 13 production areas and assigns the codes green, yellow or red to each area depending on their performance on predefined environmental criteria set by the government. Based on assigned codes, each production area may be allowed to increase its production (green light), freeze its production (yellow light) or required to reduce production (red light). If the environmental criteria are satisfied within a region, the region can grow by a maximum of 6% for every two-year period – a quantity which is to be distributed between existing and new licenses (The Norwegian Government, 2015a; Marine Harvest 2016; Intrafish, 2017b). Thus, the producers shall be encouraged to take responsibility for the area in which they produce, and good practices and routines will be rewarded with growth (Nrk.no, 2017). The division into 13 areas is based on scientific research by the Norwegian Institute of Marine Research (IMR), undertaken to model ocean currents and the spread of sea lice along the cost. Using cluster analysis, a statistical technique, they separated the coast line into areas in which sea lice tended to spread within but not between (IMR, 2015).

With respect to land based production in Norway, a recent change to industry regulations has served to substantially lowering barriers to entry in land based salmon aquaculture, while simultaneously eliminating restrictions on the production of smolts. Per June 1st, 2016, the Norwegian Directorate of fisheries set into force a set of new rules for the issuing of permissions to establish land based aquaculture operations in Norway (The Norwegian Government, 2016; the Norwegian Directorate of fisheries, 2016). Most importantly, it was opened for operating licenses to be issued continuously and without proceeds (apart from a processing fee, which remains). The application procedure is decentralised to the county level, where the relevant county processes applications and issues licenses to operate continuously. The changes were implemented based on recommendations made in the previously cited report “Salmon on land” by Holm *et al.* (2015), where a working group was given the mandate to explore the status of land based aquaculture and to recommend any changes needed to lower barriers to this type of aquaculture operations – if recommendable. Following the recommendations, the described changes were implemented, while former restrictions on smolt weight were also abolished (the Norwegian law of aquaculture, Chapter 5 §55).

2.4. Land-based aquaculture

As illustrated in this chapter, a combination of high salmon prices, increasing production cost in traditional sea pen farming and encouragements from the government to innovate and explore new technologies have all contributed to drive forward the development in land based aquaculture and other technologies (which will not be discussed here). As the costs and risks of keeping fish in the sea have increased in Norway, adaptations to production include keeping the salmon on land for longer. As shall be described later, other countries are moving in the same direction. Not only is traditional salmon production getting more expensive, but land based competitors are attracted by the opportunity to avoid license investments and potentially eliminate transportation costs by locating closer to major markets (savings of as much as NOK 13-18 per kg by air freight to the important Asian and US markets, by some estimates – see e.g. DNB Markets 2017; ilaks.no, 2016[a]).

2.5.1 Land-based aquaculture technology

Closed containment technologies have become a major focus of aquaculture research and development (House of Commons Canada, 2013). Closed containment systems (CCS) describe aquaculture facilities on land or in the sea that have a separating barrier between the fish and the environment around the facility. Land-based aquaculture systems is one of these technologies, which has come into focus as a means of protecting both farmed and wild species from issues such as genetic interaction and disease.

The (modern) history of land based aquaculture technology began in the mid-late 19th century, when fish hatcheries and fish culture facilities originated in Japan, Canada, Norway and the United States to restock declining commercial and recreational fish stocks (International Salmon Farmers Association, 2016). Traditional land-based aquaculture systems have been based on a flow-through technology, pumping water into the tanks and using it only once (Holm *et al*, 2015). However, the past 20-35 years have seen a considerable development within recirculation technology (Holm *et. al,* 2015; Liu et al, 2016). First trialed for carp in Japan in the 1950s, recirculation aquaculture systems (RAS) underwent a revival in the 1980s as technological advances made them more viable (Intrafish, 2015). RAS, where 95-99% of the water is reused, have become increasingly popular ever since (Holm *et. al,* 2015).

Compared to the earlier technology, the RAS systems require substantially less water, have lower costs of pumping and energy, are assumed to provide better control with the production environment and new solutions for reduction of waste disposal to the sea. According to industry sources[24], the major benefit of using recirculation technology is that it provides stable, environmentally controlled conditions for rearing fish in terms of temperature, oxygen content, pH and overall water quality. This in turn promotes greater fish health, better quality, superior growth rates, improved feed conversion ratios, reduced disease outbreaks and lower

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[24] Jacob Bergnballe, business director of land based aquaculture for Akva Group, one of the world's largest providers of RAS systems (Intrafish 2015).

use of therapeutants (ibid.). Supporters of the technology envision environmental gains through eliminating interactions with wild species, improved fish health, better growth rates and zero emissions through the reuse of energy, water and waste (Liu *et al.* 2016). Moreover, the development of RAS internationally has made possible the establishment of land-based aquaculture of fish for human consumption on locations formerly not considered, including the opportunity of locating production closer to major markets (ibid.).

Currently, advanced reuse systems represent only 4.5% of the total aquaculture market (Basu, 2015). RAS systems currently account for 6 percent of total production in China and 12 percent in both the United States and Europe (ibid). By 2030, Basu (2015) predict that RAS will produce over 40% of the total aquaculture output. According this study, Europe is poised to become a leader in water recirculation systems.

Besides the optimistic predictions stands a substantial global track record of company failures in using RAS, for reasons including economic viability, biological challenges and difficulty of operating the systems at commercial scale (Intrafish 2015). When it comes to technology diffusion at a large scale, many uncertainties remain about cost competitiveness, regulatory support and access to financing and resources, including coastal land, water and energy (International Salmon Farmers Association, 2016). RAS technology has come a long way over the past 30 years but is still at an early stage of development for large-scale commercial grow-out, particularly of marine species (Intrafish, 2015)[25]. Nevertheless, it is expected that the economic barrier to using RAS gradually should be lowered as technology improves and economies of scale are realised (Intrafish 2015; Iversen *et. al*, 2013; Liu *et. al*, 2016).

In hatchery and fry systems, RAS technology is already being applied all over the world (Intrafish, 2015). Opportunities to give fish the best conditions when they are young result in healthy juveniles that experience fewer problems during grow-out. Although new and unfamiliar challenges may show up in relation to new technology, it is believed by many that RAS offers the potential to exercise considerable control over the aquaculture environment so that optimal growth and fish health conditions may eventually be achieved and sustained in such systems. With greater control over critical elements of the production process, this could

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[25] In the seabass and seabream sector, there is increasing use of recirculation systems for grow-out and it has long been common for trout to be farmed from egg to harvest using the system. In the Middle East, projects are being developed for seabream, grouper and barramundi. However, for larger-scale production of tilapia, which is particularly relevant in China, systems need to become larger and cheaper to become attractive and profitable (Intrafish, 2015). High-value species such as shrimp are also targeted for production in RAS, after seeing substantial sustainability and disease issues in pond based aquaculture (East Asia Global Alliance, 2014)

in turn reduce mortality while shortening the production time in sea, including for salmon (ibid.).

2.5.2 Land-based salmon aquaculture

With ongoing technological improvements, freshwater aquaculture of salmon from eggs to harvestable sizes of 4–5 kg in land-based systems (particularly RAS) is increasingly receiving attention from the industry, investors, regulators, academics and the press, evaluating its potential as a viable production technology (Liu *et. al*, 2016). The control and flexibility offered by RAS may offer certain advantages over salmon operations in open sea-pen systems, which require expensive licenses, are negatively impacted by sea lice, dependent on access to suitable coastal sites and typically has a relatively long transport distance (and high transport cost) to supply important markets (ibid).

2.5.2.1 The state of land-based salmon aquaculture

In salmon aquaculture, the production of fish for human consumption is as noted carried out mostly in sea, while the first phase of fingerling production, typically up to a size of approximately 100 grams, takes place on land. Smolt producers are increasingly extending the land-based production phase, allowing for increased smolt size before the transfer to the marine environment (ISFA, 2016). For this purpose, the salmon aquaculture industry increasingly invests in technological improvements to land-based salmon farming systems and RAS, recognising that it may have a potentially valuable role to play for the future salmon production (ibid.). For instance, Marine Harvest reports that the majority of their investments currently go into the development of its freshwater sites for smolt production (Intrafish, 2016[a]). Bakkafrost, a Faroese salmon producer, is increasing investments in hatcheries to reach its long-term goal to raise the smolt size to 400-500 grams per fish by 2019 (Intrafish 2016[b]). Grieg, another salmon producing firm, has presented their new strategy of reducing the salmon production time from 24 months to 18 months by releasing bigger and stronger fish to sea-pens and thereby reducing risk and exposure time in sea (Intrafish 2016[c]).

Because of the control of important parametres such as temperature in land based facilities, the length of a production cycle can be considerably shorter when producting larger smolts before release to sea. A prolonging of the initial land based phase leads not only to an overall reduction in production time, but also a much shorter exposure time in sea. This gives rise to the benefits of lower production risk, less exposure to sea lice sea and lice treatments and shorter periods between fallowing of production sites. Parasites and diseases will have less time to accumulate before a site is emptied, and infected fish may be harvested instead of receiving treatment. Moreover, the long production cycle in traditional production means that the fish are exposed twice either to the unfavourable periods of the lowest temperatures and the slowest growth or to the unfavourable periods with the highest risk of sea lice infection. By extending the land based phase before release to sea, these issues are addressed, while production risks may presumably be shifted to some extent from factors outside of the farmers control to more manageable and controllable production risks.

As traditional farmers are extending the production phase on land, similar production modes may also be adopted in unconventional areas. Notably, in South Korea the country's first salmon has been delivered to market, using post smolt (200-400g) combined with sea based grow-out (Korea Herald, 2016). While the producer aimed at supplying 400 tonnes by year-end 2016, it hoped to increase its production to 10-20,000 tonnes by 2020 (ibid.).

DNB Markets quantify the growing number of RAS facilities for smolt in Norway, as producers recognise the advantages of reducing time fish spend in the sea. The number of RAS facilities increased to a total of 90 in 2016, up from around 20 three years earlier (DNB Markets, 2017). Equipment providers report activity higher than ever with large backlogs on new projects (ibid.). With an increasing number of RAS facilities, it follows that investments in new technology have been substantial (DNB Markets, 2017). Technology improvements following smolt producers demand for larger facilities for larger smolts may in turn have contributed to the feasibility of extending land based aquaculture further towards full land based grow-out (ibid.). As illustrated in chapter II (figure 2.10), investment in smolt and fry production rose considerably from 2004 to 2015.

Land-based farming of salmon for human consumption still has a minimal scope globally. In 2007, at least 40 trials with capital investment exceeding $283 million had been conducted on for production of Atlantic salmon at harvestable sizes around the world (Canadian Science Advisory Secretariat, 2008). Yet, as of 2016, only one Danish facility was close to reaching an annual production level near 1,000 tonnes (<700), while the minimum efficient scale is probably quite a bit higher than that. As the former sections revealed, this has not stopped interest in land based salmon aquaculture facilities from rising. On the contrary, a number of commercial land-based farms are being planned, built and set into operation in Europe, North America, China, and Norway (Liu et al, 2016). Billund Aquaculture Service, a leading supplier of land based aquaculture technology, report "huge request" for land based salmon and trout grow-out in RAS (Olsen, 2017). The company reports making at least one quote for projects on a weekly basis, with requests from at least 15 countries including from Europe, Asia, North America and Africa[26].

A look at planned land based projects suggest that the collective impact on the industry supply could be substantial if the expansions are realised. DNB Markets (2017) calculated that the planned salmon production capacity from 20+ identified land based projects amount to 150 thousand tonnes in early 2020, potentially making land based salmon among the major salmon supply sources if the plans are successfully carried out[27]. Among the projects identified by DNB, the majority is based on RAS technology and originate in regions familiar with salmon production; the Nordics, Canada and the US, presumably with links to existing knowledge hubs.

Nofima, a Norwegian research institute at the forefront of land based aquaculture trials and biological research, carries out full cycle grow-out and has undertaken both biological, economic and market related studies of land based salmon and post smolt. The researchers emphasise the potential of RAS in addressing industry challenges such as escapees, disease and sea lice (Nofima, n/d).

Trials and experiments with full grow-out of Atlantic salmon on land continue around the world at various rates of expansion, and thus far with various degrees of success. This may be due to a number of factors, including the level of understanding with respect to the biological needs in land based systems, new challenges including bacteria and water management, differences in regulatory support, cost and market conditions, access to financing and other resources including land, water, energy, knowledge and competent labour and other inputs. Nevertheless, as research progress and the few companies in operation continue to address and resolve biological and other challenges while newcomers continuously appear, the learning curve may well be steep in the land based production sector for the time to come.

2.5.2.2 The economics of land-based salmon aquaculture

A few studies have performed comparative economic analyses of closed-containment options including land-based technologies, exploring their economic feasibility in relation to the conventional production approach. In the following, a brief review is presented of some of the studies that have undertaken economic comparisons of land-based production and traditional

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[26] Billund Aquaculture: Global Trends in Commercial Salmonid RAS. Presentation at TEKSET, a conference, February 15, 2017 in Trondheim, Norway.

[27] After Norway and Chile, the UK and North America (Canada) constitute the major supply sources, each of the latter two with respective production of around 150 thousand tonnes annually in 2015 and 2016 (Marine Harvest, 2016). It should be emphasised that out of the 150 thousand tonnes planned, three major projects (each of 30-40 thousand tonnes) constitute around 100 thousand tonnes of the identified total production (DNB Markets, 2017). The projection does not count potential increases from combined production modes (post smolt).

sea-pen operations. Their findings with respect to initial investment is first provided, followed by comparative costs of production. A notable challenge in trying to compare and assess the findings is that each study is carried out under various assumptions, for a particular production capacity, with varying equipment and components and in a specific context. Moreover, it is important to note that in common with the current study, all are engineering studies, meaning that estimates and data are highly uncertain. To the best of our knowledge, no analysis based on actual data from large, full-scale facilities exist (simply because such operations at has yet to be established).

The findings of the studies broadly align with respect to assessments of risks – concluding that land-based production involves a larger degree of uncertainty (King *et al*. 2016; Iversen *et al,* 2013; Boulet *et al,* 2010). King *et al.* (2016) found that the financial risk, as shown by the level of uncertainty of the result, was greater for land-based RAS production technology than for three alternative production approaches analysed. This assessment is consistent with the findings of other analyses (e.g. Boulet *et al,* 2010; Iversen *et al,* 2013 and Liu *et al,* 2016).

The study by King *et al.* (2016) was conducted with a focus on Tasmanian aquaculture operations, where each of the production scenarios were developed with an annual capacity of 6,000 tonnes HOG production. Their findings indicated that the initial capital investment required for land-based RAS was approximately two times greater than the equivalent investment for inshore sea-pen production.

Boulet *et al.* (2010) analysed and compared the economic feasibility of five production approaches, including conventional net-pens, in the context of the Canadian industry within the operating environment in British Columbia. Assuming an annual production of 2,500 tonnes, they estimated initial investment requirements in RAS more than four times the requirements for inshore sea-pens.

Liu *et al.* (2016) modelled production facilities of 3,300 tonnes for sea-pens and RAS, respectively, and estimated capital investments of approximately $30 million for sea-pens and approximately $54 million for the RAS system, i.e., less than two times as much (a difference of 80%). Their data was based on Norwegian salmon farmers' operations in the sea-pen scenario, while the land-based scenario was based on data developed by The Conservation Fund's Freshwater Institute grow out trials of Atlantic salmon in RAS.

Iversen *et al.* (2013) compared five alternative production approaches in a Norwegian context. Investments in the base case, inshore net-pens, was estimated at 220 NOK per m^3 of production volume – based on actual numbers from a group of Norwegian firms with annual production of 8,800 tonnes per company. The RAS facility assumed a production of 3,300 tonnes per annum and investments of 10,000 NOK per m^3 of production. Production density/productivity for the two alternatives were respectively 30 kg/m^3 in net-pens and 180 kg per m^3 in RAS.

With regard to findings about cost of production, King *et al.* (2016) emphasised the high uncertainty in modelling cost of production in RAS. Nevertheless, using statistical simulations (Monte Carlo simulation), they estimated that around 90% of the simulated RAS grow-out would have a superior cost of production compared to Tasmanian south-east inshore sea pen production. The steady state cost of production was budgeted to AU$ 5.12 per kg in RAS compared to AU$ 5.65 in sea pens, which is a difference of 9.4% to the advantage of RAS.

According to Liu *et al.* (2016), the total operating costs for the two systems were relatively similar, with RAS only 10% higher than the sea-pen system. Without interest and depreciation, the two production systems seemed to have an almost equal operating cost, 4.30 US$/kg for sea pens and 4.37 US$/kg for RAS. Conversely, Boulet *et al.* (2010) estimated cost of production to be higher in RAS than in sea pens, with a disadvantage of 18%. Iversen *et al.* arrived at the same conclusion, estimating a cost disadvantage in RAS of 27.6%. On the other hand, Rosten *et. al* reported somewhat lower production costs in RAS, where total production costs were estimated to $ 14 million in sea-pens (corresponding to $ 4.24 per kg) and $ 13.1 million in RAS (corresponding to $ 3.97 per kg) for production of 3,300 tonnes (King *et al.* 2016). In this case, the estimated cost advantage in favor of RAS amounts to 6.6%. A recent report by DNB Markets (2017) estimated that the land based cost of production is approaching that of conventional Norwegian sea pens, estimating cost of production in land based salmon farming to NOK 37 per kg, with the corresponding number for sea based production in 2016 being NOK 36 per kg.

As the discussion illustrates, results and findings vary widely. Apart from the fact that actual data cannot be obtained, this is likely to be a result of differences in assumptions, operational design, time period of the studies as well as the context (geographical location), involving actual differences in the same concepts depending on location. It is noted that comparability between studies is complicated due to differences in scale, country and regulatory environment, costs (e.g. energy costs between countries), difference in treatment of costs and investment (notably the value of sea based licenses, which seems disregarded in many studies), biological assumptions, whether the analysis includes harvesting and/or primary processing and more.

2.5 Summary

It is clear from this review that while interest in land based salmon aquaculture is increasing, views on its viability and how it is likely to unfold diverge. Moreover, academic literature on the economics of land based aquaculture is rather limited. Indications suggest that both the cost of production and necessary investments are converging somewhat between traditional and land based aquaculture, but the evidence remains scarce, and estimates rely heavily on assumptions. Production cost estimates for land-based facilities are engineering studies rather than data based, as such data in practice still does not exist. Without empirical data, it follows that the uncertainty is large. Nevertheless, with high salmon prices, binding regulations and limited supply growth, increasing costs and biological challenges in traditional farming, the risk-reward is looking attractive enough for investments in land based salmon aquaculture already to have started to take off.

Meanwhile, traditional farmers are increasingly interested in deploying the benefits of land based technology in combination with sea based net pens and their "natural competitive advantage". To direct well-informed expansion and to better understand the potential impacts of new technology on the industry as we know it, more knowledge is needed about the economics of land based aquaculture. This study will contribute to the discussion by examining the economic competitiveness of land based salmon production models in terms of cost of production and potential profitability of investments (NPV).

We now turn to a discussion of the methodology to be applied in the analyses. Methodology is presented in chapter III.

III. METHOD

3.1 Introduction

The analyses to be undertaken in this study aim at investigating investments in land-based farming of salmon. Extending knowledge about the economic competitiveness of new technology is of relevance for strategic decision making by companies and policy makers, as increasing amounts of investment is seen to be flowing into the construction of land-based salmon farms globally. Two main methods are applied: investment analysis (net present value (NPV) and internal rate of return (IRR)) and steady state cost analysis. Both to provide fundamental insights into the questions of economic returns and profitability.

The study analyses two main scenarios: 1) full land based production of salmon up to a harvestable size of about 5 kilograms and 2) "post smolt" – an extension of the initial land-based smolt phase. The post smolt scenario looks at release of post smolts to sea at 400 grams and 600 grams, respectively, instead of the traditional release at a size of about 100 grams. The alternatives are compared to the traditional production model.

Because of the long production cycle for salmon to grow from hatching of eggs to a harvestable size, it may take several years from the development of a farm until it reaches full production (Asche & Bjørndal, 2011). To analyse cost of production, a steady state situation is assumed, meaning that the farm is fully operational (ibid.). This provides an important indication about the price the firm will need to fetch in order to be financially viable over time (ibid.). This complements the NPV analysis by providing more interpretable information about the cost competitiveness among alternative production modes and a basis to assess cost of production in relation to market prices.

The scenarios are analysed and evaluated in relation to the objective of maximising efficient use of society's resources. That is, it seeks to evaluate the profitability of the alternative production modes without consideration of taxes and subsidies, which from a private perspective might affect or distort relative attractiveness. From the public's perspective[28], these items are irrelevant.

The following sections of this chapter present the theoretical framework underlying the main analyses. Section 3.2 is a review of the logic behind investment analysis: net present value (NPV) and internal rate of return (IRR). In section 3.3, the concept steady state cost analysis is explained in more depth. In analysing the specific problem at hand, two characteristics require

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[28] For the purpose of this paper, the terms private perspective and public perspective are used to distinguish between the public, i.e., governmental sector versus the private sector and should not be confused with the same terms used to distinguish publicly (listed) and privately (unlisted) held firms.

particular attention; namely the risks and uncertainties related to new technology and the reliance on biology and fish welfare. The approach to dealing with these issues is discussed in section 3.4, where the primary focus is on the use of appropriate discount rates and sensitivity analysis. A brief summary is given in section 3.5.

3.2 Investment analysis

This section focuses on capital budgeting, the decision-making process for accepting or rejecting projects (Ross *et al*, 2008, 161). Ultimately, a good capital budgeting criterion should tell two things: First, whether a particular project is a good investment; and second, if having to select one among several good projects, it should make clear which one should be selected (Hillier *et al*, 2014, 191-218). Among the commonly used investment rules are net present value (NPV), the internal rate of return (IRR), the benefit/cost ratio or profitability index (PI), the payback method and the return on capital employed (ROCE) (or average accounting profitability (ARR))[29] (Ross *et al,* 2008, 161-183; Lumby and Jones, 2015, 28-119; Hillier *et al,* 2014, 191-218). Because of major weaknesses in the latter two techniques, the analysis centres on NPV, using IRR as a supplement but with a brief discussion of the benefit/cost ratio as well.

NPV is generally held as the only investment appraisal technique which gives consistently reliable advice to both questions raised above (Ross *et al*, 2008, 161-183; Lumby and Jones, 2015, 28-119; Hillier *et al.* 2014, 191-218). As explained below, the decision rule holds even when the alternatives are of unequal magnitude, duration or risk, if only the discount rate properly reflects the return available to the investor from a similar-risk investment. The internal rate of return (IRR) is a related concept to NPV and is defined as the discount rate that gives a NPV equal to zero.

3.2.1 Net present value (NPV) and Internal rate of return (IRR)

An investment involves sacrifices today in the expectation of benefits in the future. For potential investors in a salmon farm, what is of interest is whether they will achieve an acceptable return on the invested capital (Asche & Bjørndal, op.cit, p. 211). To value cash flows that occur at

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[29] Investment decision rules such as the payback method and the return on capital employed are commonly applied, but fail to take account of central aspects of investment appraisal. Most importantly, the payback method fails to consider the entire lifetime of the project beyond the time required to repay the investment. The return on capital employed (ROCE) has a fundamental weakness in that it is based on accounting profits and fails to take account of the time value of money. Accounting was designed to provide evidence that people managing other peoples' assets and capital could account for them. Consequently, accounting profits are produced using a number of conventions and rules, supporting its function as a reporting device, not a decision-making device (Lumby & Jones, 2015, 3-11).

different points in time over a project's horizon, the net present value (NPV) method of investment appraisal is applied, where the NPV of an investment is defined as the difference between the present value of benefits and the present value of costs (Bøhren & Gjærum, 2009). The NPV decision rule states that a project should be accepted if the NPV is positive, because accepting the project is expected to increase the owners' net wealth by a magnitude equal to its NPV (ibid.). If several, mutually exclusive projects are under evaluation, the NPV decision rule is to accept whichever project has the largest positive NPV (Lumby and Jones, *op. cit*, 28-119). Thus, net present value is a measure of how much value is created or added today by undertaking an investment (Hillier *et. al*, 2014, 191-218).

The IRR of a project can be defined as the rate of interest which, when applied to the project's cash flow, produces a zero NPV (Lumby and Jones, *op. cit*, 73). In the analysis, the estimated IRR is included as a complement to NPV. As NPV is sensitive to the interest rate, the additional information provided by IRR may be of interest. Most importantly perhaps, the IRR offers investors an indication of the maximum interest rate the project could handle if it was financed by debt.

The decision rule in using the IRR is as follows: Accept only projects with an IRR greater than or equal to the interest rate (ibid, 76-77). The reasoning behind the IRR decision rule is similar to that behind NPV: to be acceptable, a project must generate a return at least equal to the opportunity cost of capital involved.

3.3 Steady state cost analysis

To analyse cost of production, a steady state situation is assumed, meaning that the farm is fully operational (Asche & Bjørndal, *op.cit*). Because of the long production cycle that is required for salmon to grow from hatching to harvestable size, it may take up to several years from the development of a farm until it reaches full production (Bjørndal *et. al*, 2015). A farm may also release several batches of juveniles in a year to have harvestable fish throughout the year (ibid.). Provided the pattern of releasing and harvesting fish remains unchanged over time, the total amount harvested in one calendar year will be the same as the total harvest from a year's total releases (Asche & Bjørndal, *op.cit*). For this reason, the analysis in steady state can be based on consideration of one year's release. The practical process of calculating the average cost of production is best described in a later chapter using actual data.

As noted earlier, the production cost per kg shows what kind of price the firm must fetch in order to remain profitable over time. It also reveals important information about the composition of production costs, which is not easily inferred from the NPV analysis and makes an interesting point of comparison among the alternative production modes. Knowledge about differences in the composition of costs may also contribute insights into potential improvements in efficiency. Thus, although NPV and the cost of production are closely related, the analysis of production costs per kg complements the NPV analysis by providing more interpretable information about cost competitiveness.

3.4 Risk and uncertainty

Various industries and investments exhibit different degrees of risk. In land based salmon aquaculture, one can identify production risk, technological risk and market risk, in particular about the level of prices in the future (Asche & Bjørndal, *op.cit*). For the investor to make a rational investment decision, a comprehensive understanding of the investment alternatives' likely outcomes is required to anticipate cash flows and assign each project an appropriate value. In analysing the specific problem at hand, two characteristics require particular attention; namely the risks and uncertainties related to new technology and the reliance on biology and fish welfare.

As chapter II demonstrated, the salmon farming industry is a relatively young industry, where the land based fresh water production phase historically has been limited to smolt production (<100 g). Only recently have investments in land-based facilities dedicated to the "post smolt" life stage of salmon begun to take off, as improved land-based technologies are developed and dispersed. Due to the novelty of the technology, investors have limited data available when undertaking investment decisions. Limited experience data along with continuous development of the technology means that there is high technological uncertainty involved. Moreover, the project's success relies on the biology of the fish, parts of which are not fully understood. Accordingly, growth and mortality in land based aquaculture environments constitute a major factor of uncertainty. Although land based facilities offer opportunities for increased control of the aquaculture environment, this also puts high demands on the salmon farmers' knowledge, competence and ability to create an optimal ecological environment.

The many unknowns require special attention to the treatment of risk. In making recommendations on the discount rate for use in the evaluation of public investments, a Norwegian committee has established some general guidelines (NOU 2012:16.). The Committee decided not to recommend the establishment of several risk classes with different risk-adjusted discount rates. This recommendation is also followed in the current study.

In terms of the level of the discount rate the committee concludes: there is no one correct way of providing specific estimates for the risk-free market interest rate, the risk premium and the time profile of interest rate developments. However, a reasonable approach may be to assume that it will, under normal market conditions, be possible to secure a risk-free real interest rate of 2.5 percent within a time span of 40 years through investments in the international financial market. Thus, the committee recommended discount rates as presented in table 3. In this study, the discount rate is therefore set at 4% (chapter IV). It should be noted that all rates here are real.

Table 3.1: Recommended discount rate structure for an ordinary project.

	Discount rate		
	Years 0-40	Years 40-75	From year 75
- Risk-free rate	2.5 percent	2 percent	2 percent
- Premium	1.5 percent	1 percent	0 percent
Risk adjusted rate	4 percent	3 percent	2 percent

Source: NOU 2012:16.

If one would otherwise like to conduct a sensitivity analysis to examine how the net benefits from the project are influenced by other assumptions, the recommendation states that it is appropriate to do so as a supplement, thus retaining a basic analysis that ensures comparability in the decision-making process (ibid.). This way, the treatment of risk should be more transparent, and the possibility of double counting risk should be reduced. Sensitivity analyses are applied to both cost of production analyses and investment analyses in this report.

With the theoretical foundation in place, the following two chapters will apply the methodology to the analysis of the two main scenarios: full production cycle for salmon on land and production based on post smolt[30].

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[30] Appendix B explains the methodology used to estimate growth curves, the thermal growth coefficient (TGC).

IV. LAND BASED SALMON – FULL GROW-OUT (5 kg)

4.1 Introduction

This chapter will analyse a land based salmon farm with an annual production capacity of 5,000 tonnes (live weight) for full grow-out of salmon. The facility is assumed to run its own hatchery, so that the salmon is grown on site from roe and up to a harvestable size of 5 kg. The technology used is that of recirculating aquaculture systems (RAS), as described in chapter II. Accordingly, the challenges emphasised in chapter III with regard to data are of great relevance, as the technology has yet to be applied to full cycle grow-out for a production of this scale. It follows that knowledge about important parameters relating to growth and mortality is limited. Assumptions about economic and biological variables and parameters are based on information from and meetings with the industry and research centres and will be presented in the following. The methodology is based on Asche & Bjørndal (2011), see also Bjørndal *et al.* (2015) for an application to farming of sole.

The chapter is organised as follows: First, an overview is given of investments, amortisation periods and depreciation for a land based facility. Second, a production plan is presented for an annual production of 5,000 tonnes of harvestable salmon (5 kg). Based on the above, assumptions are presented about operational costs, followed by estimation of the company's cost of production per kg. Finally, the investment analysis will be carried out to estimate expected NPV. A number of sensitivity analyses will be undertaken for both of the latter steps, analysing the impacts on both cost of production and NPV from changes to certain parameters.

All monetary values in this chapter are in 2017 Norwegian kroner (NOK), unless otherwise notified.

4.2 General assumptions

There are some general assumptions that will be used in all the economic analyses in chapters IV and V. These will be given and justified here.

Economic

Interest rate:	4%
Labour cost per labour-year:	NOK 665,000
Manager	NOK 975,000
Insurance fish:	2.5% of cost of production.
Insurance facility:	Building 0.6 ‰ of value

Machinery and equipment: 2.5‰ of value

The same interest rate will be used for all capital invested including working capital. This means we need not be concerned about capital structure and financing. With reference to the discussion in chapter III, the interest rate is set at 4%. It should be noted that this is a *real* interest rate[31].

The cost per man-year is based on wage statistics for salmon aquaculture for 2015, which has been adjusted to 2017-price level[32]. The premium for fish insurance[33] assumes a deductible of 20%. An increase in the deductible to 30% would involve a saving of 15-20%. For both fish and facility insurance it is important to note that there may be substantial differences from customer to customer, depending on claim history, location, type of facility etc.

It should also be noted that the cost of production is always referring to farm gate cost, so that costs related to harvest, sales, transport etc. are not considered.

Biological

All the economic analyses will be based on a biological model describing the development in weight and mortality over time. To ensure comparability of results, the basic underlying biological model will be the same in all alternatives. The basic assumptions are as follows:

Growth up to 92 g: Based on information from industry sources.

Month (beginning)	Weight (g) per fish
0	0,2
1	0,8
2	3,1
3	8,0
4	24
5	50
6	92

This part of the grow-out phase is similar in all cases, and the industry has much experience with land based smolt production up to this size. Throughout the initial phase, both land based

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[31] In 2016, inflation in Norway measured by the Consumer Price Index (CPI) was 2.9 %. Thus, a real interest rate of 4% corresponds to a nominal interest rate of 6.9%.

[32] SSB (2016): Annual salary (NOK) for occupation 6221 aquaculture worker, full-time employees, private sector: 640,900 incl. 30% social costs. This figure is for 2015 and has been adjusted to 2017 level to account for wage increases (CPI 2015 = 100, January 2017 = 104.2).

[33] Insurance premiums have been obtained from a large insurance company. As there is very little experience when it comes to insuring land based farms, the premiums are uncertain and depend on several matters including deductibles.

and combined production modes (post smolt) are assumed to keep the fish in land-based facilities with the same degree of control over temperature, water and other parameters. Hence, both scenarios share the same initial weight curve given above.

Growth from 92 g +:	Calculated based on thermal growth coefficients (TGCs) obtained from Nofima and published sources. The thermal growth coefficient (TGC) is explained and discussed in appendix B. Land based temperatures are assumed to be 12 degrees Celsius, while sea based temperatures are based on average monthly observations from the research station of Bud (see appendix B, table B1a and b).
TGC land based:	2.7
TGC sea based:	2.2 for one month after release to sea, thereafter 2.7 up until harvestable size.

Several studies (Nofima; Austreng *et al.* 1987; Thorarensen & Farrel, 2011) suggest that it is reasonable to assume a TGC of about 2.7 for Atlantic salmon. A TGC of 2.2 for the month of release is based on advice from Nofima[34] in order to take account of the need of the fish to recover after the stress that may result from transport and handling and adapting to a new environment.

4.3 Investment assumptions

We will first consider investments required for a 5,000-tonne facility. These investments are difficult to determine, as there are no farms with this production capacity in operation. Nevertheless, according to industry sources, it is believed that investments may vary between 80-90 million NOK per 1,000 tonnes production capacity for an operation of this scale (DNB Markets; communication with industry participants), while there are also indications that investments may be higher than that and may also depend on scale. In table 4.1 information is given about expected investments in farms ranging in size from an annual output of 1,000 tonnes to 5,000 tonnes based on RAS technology. The information is provided by a leading supplier of this technology. While a 1,000-tonne farm would require investments of NOK 150

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[34] Based on personal communication and advice from Bendik Fyhn Terjesen, senior scientist at Nofima's research center in Sunndalsøra, Norway.

million, this increases to NOK 578 million for a 5,000-tonne farm. In all alternatives, RAS equipment is the largest share of the investments, followed by buildings and concrete work (RAS and fish tanks).

Table 4.1: Investments in land based farms from 1,000-5,000 tonnes. NOK ‘000.

Investment (NOK)[a)]	**1000t**	**2000t**	**3000t**	**4000t**	**5000t**
Buildings	41,424	66,218	86,616	113,433	159,062
Electrical installations	9,212	17,001	20,169	26,414	31,553
Other installations (ventilation etc.)	7,646	13,935	14,953	19,583	22,131
RAS equipment	67,179	110,249	156,395	204,815	245,902
Concrete work (RAS and fish tanks)	19,302	62,854	70,378	92,167	108,608
Various	5,013	5,574	6,955	9,108	10,820
Total investment	149,776	275,830	355,467	465,520	578,076
Investment NOK/kg production	**149.8**	**137.9**	**118.5**	**116.4**	**115.6**

a) Note: Values are originally in Euros (€) and have been converted to NOK using the 2016 average NOK/USD exchange rate: 9,2899 (the Central Bank of Norway).

Source: Billund Aquaculture Service A/S.

Investment per kg of production capacity gives an indication of economies of scale in production. Investment is NOK 149.80 per kg production capacity for the 1,000-tonne farm and starts levelling off for the 3,000-tonne farm (NOK 118,50/kg) to NOK 115.60 for the 5,000-tonne farm. With the exception of concrete work, all other parts of the investments appear to give rise to economies of scale.[35]

As our base case, we will use information that has been made available from one planned 5,000-tonne project. Investments, which are given in table 4.2, have been quality controlled by industry participants with some indications that they may be located at the lower end of the likely investment range (see also table 4.1 for comparison). As noted above, the technology selected is that of RAS. Total investments are estimated at NOK 429.3 million. This corresponds to investment of NOK 83.85 per kg production capacity. While this is in the range considered “normal” by many industry participants, it is considerably lower than the figures in table 4.1. As there are very few such farms in operation, this discrepancy cannot be resolved by empirical observations. We will, however, perform a sensitivity analysis so as to quantify

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[35] For a full picture of economies of scale, it is also necessary to consider other costs of production that do not increase proportionally with output such as labour and management. This will be discussed in chaper 4.5.

the consequences of different assumptions regarding investment costs when it comes to cost of production and net present value.

The main investment components are building, construction and project related work (NOK 206.6 million), aquaculture system equipment (RAS and related equipment such as piping, pumping and electric equipment, NOK 181 million), investment in land, infrastructure connection and ground water drilling (NOK 12 million). Fish management and laboratory equipment amounts to approximately NOK 6.0 million, production tanks and hardware to NOK 5.0 million while cost of planning is set to NOK 1 million.

Table 4.1. Investments and Annual Depreciation and Interest for a 5,000-tonne salmon farm. NOK '000

	Investment, NOK ('000)	**Economic lifetime**	**Depreciation and interest, NOK ('000)**
Building, construction and project related costs	206,641	20	15,205
Aquaculture system equipment (pumping, piping, filter, water treatment & electric)	180,905	20	13,311
Production tanks and hardware	5,000	20	368
Fish management, feeding and heating systems, vaccination and laboratory equipment	6,011	10	741
Land/building plot (60,000 m2) and plot development	12,000	-	480
Infrastructure connection (road, electricity, plumbing) and ground water drilling	18,000	-	720
Cost of planning, application, processing fee, etc.	1,042	-	42
Sum	429,600		30,867

Investments provide the basis for estimating the company's capital cost, represented by interest and depreciation on invested capital. As noted above, the interest rate is set at 4%. For estimation of annual depreciation charges on the physical structures that depreciate over time, the lifespan (amortisation period) is assumed to vary from 10 to 20 years for different components (table 4.1). Often, depreciation is based on a linear method or a certain percentage of the remaining value per year, which means that the annual depreciation will vary over time (Asche & Bjørndal, op.cit, 209). In this case, an annualised depreciation and capital cost is estimated according to the annuity principle, making the sum of interest and depreciation a steady annualised cost (ibid.)[36]. Land does not depreciate and therefore only interest is charged. The same is done for the cost of planning, application and processing fee related to establishing the project and obtaining an operating permission (license). As shown in table 4.1, the sum of

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[36] Annuity factors are 0,0736 for 20 years, 0,0899 for 15 years and 0,1233 for 10 years.

interest and depreciation amounts to NOK 31.7 million annually, which can be considered the average amount of depreciation and interest over time (ibid.).

With investments as outlined above, an operational farm is established with capacity to produce annual harvests of 5,000 tonnes. In the following, a production plan tailored to the facility's capacity will be outlined, providing the basis for calculating steady state cost of production.

4.4 Production plan

In salmon aquaculture, the biological process associated with growing salmon to harvestable size is the foundation of the operation. The company's production plan consists of biological variables such as hatching, smolt release, feeding, mortality and biomass growth. In turn, this constitutes central inputs to the estimation of cost of production.

Continuing with the case study, the production plan for an annual harvests of 5,000 tonnes is presented. To maintain a high capacity utilisation at all times, salmon is harvested and released to the facility on a monthly basis. Roe is delivered to the operation every month at a quantity of 113,500 eggs. Within 6-10 weeks, eggs are transformed into fry[37] which are released into tanks where they start being fed for about nine additional weeks. The monthly release of 0.2-gram fry to the "start feeding tanks" is 102,150 fish. The weight curve for individual salmon is illustrated in figure 4.1, where the salmon grow from an individual size of 0.2 g in month 0 to 5 kg by the end of month 18. Harvest is 416.8 tonnes per month starting in month 18.

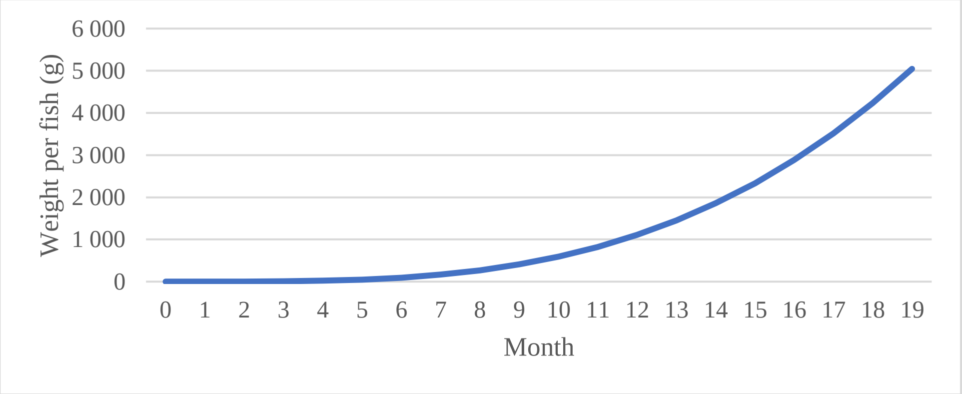

Figure 4.1: Weight curve for salmon – weight in grams per fish. Month 0-19.

Table 4.2 presents the main parameters of the production plan (with further details given in Appendix, table C1). Monthly releases of 102,150 fry give monthly harvests of about 90,000

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[37] In this period, the roe hatches and the larvae initially receive their nutrition from a yolk sac which forms part of their body. As time passes, the larvae grow while the yolk sac diminishes. When the yolk sack has eroded about ¾, the term fry is used for to describe the tiny fish which must become capable of feeding themselves.

grown-up salmon in full, steady state production, each fish at an average individual weight of 4.6 kg after 19 months of growth. The individual harvest weight will vary somewhat, as harvest is done over time throughout the month of harvest, over 19 working days. This gives a monthly harvest of about 416.8 tonnes, corresponding to daily harvests of about 22 tonnes.

Before harvest, the fish are often starved for some time[38]. This means that for a certain period, both feeding and growth is reduced. In the analysis, we simplify by assuming monthly harvest equal to the average weight per fish between the start of the harvest month and the end of the harvest month (if it is fed) times the average number of fish in the month given the assumed mortality. In the month of harvest, feeding is calculated on the basis of half of the average number of fish being fed (if no harvest was undertaken).

Table 4.2. Production plan

Fish harvest size	4.6 kg (range 4.2-5 kg throughout month 18)
Production period	Hatchery: 6-10 weeks to 0,2 g (start feed)
	On-growing: Release of 0.2 g fry in month 0, with harvest in month 18
Monthly purchase of roe	113,500 eggs
Mortality	Hatchery (from egg delivery to 0,2 g): 10%
	Mortality in the initial start feeding month: 4%, then subsequently 0.5% per month. Over the life cycle, this gives a total mortality of 21% (including the roe stage), whereof 14% occurs up until a fish size of 3 g
Number of 0.2 g fry released	102,150 fry per month
Price of roe	NOK 1.00 per egg (range 1-1.6 depending on breed)
Vaccination	NOK 1.8 per vaccine (range 1.5-2 per vaccine depending on contents) On average 95,877 fish per batch (monthly vaccination at 71 g)
Annual production	5,000 tonnes
Harvest	Monthly harvest is 416.8 tonnes, starting from month 18 (year 2).
Biological feed conversion ratio (FCR)	0.9 in months 0-11 (800 g), then subsequently 1.1
Annual feed quantity:	5,383 tonnes (appendix C), given the assumptions above

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[38] In land based aquaculture, it is also often necessary to allow for a pre-harvest practice called purging, where the fish are held in flow-through tanks for about two weeks before harvest. The reason for this is that some particles that accumulate in RAS systems cause the salmon flesh to get an "off-flavour", sometimes described as a muddy taste. These particles are removed from the fish when it is allowed to swim for at least two weeks in flow-through tanks, with constant water exchange rather than recirculation. The process happens faster if the fish gets exercise in the tanks, preferably with currents at the speed of one fish-length per second, which is indicated to shorten the required purging time by up to 40% (Nofima).

Feed price	NOK 14 per kg

Sources:
Salmobreed for egg price.
EWA Consulting and industry sources for price of vaccines and feed.
Industry sources (0.2 g – 92 g) and Nofima (92 g +) for growth data and biological FCR.
A combination of company sources and own judgement for mortality assumptions.

On the basis of this production plan (see appendix, table C1), the annual feed quantity is estimated to 5,383 tonnes which gives an economic FCR of 1.08. Given a feed price of NOK 14 per kg (table 4.2), this gives an annual feed cost of NOK 75,36 million when fully operational.

Assumptions about other costs are given in table 4.3. The required number of full-time workers is estimated 16 in the hatchery and production departments. Given labour costs of NOK 665,000 per person-year, annual labour costs amount to NOK 10.64 million. As the table shows, several cost categories including feed, oxygen and wastewater treatment are directly related to the quantity produced. The consumption of water depends on the technology and the production quantity in order to maintain the desired water quality. In this example, investment in a water well is assumed (fresh ground water), so that there are no direct costs associated with water intake and consumption apart from electricity costs[39]. Alternatively, water may be purchased from the municipal water system at a price of about NOK 7 per m^3. Variable costs such as office and administration, service, maintenance and repairs are somewhat more loosely tied to production quantity.

In addition, fixed costs of management (four managers) amount to NOK 3.9 million. Because of the long production period for salmon where capital is tied down in the biomass production process, the operations also require large investments in working capital.

Table 4.3. Cost Assumptions.

Cost assumptions:	
Variable costs	
Number of man-years	16 in production
Electricity	NOK 1 per kwh. (including “network rental fee” and “electricity fee”) 4 kwh per kg of production (range 3-4 kwh per kg) 20 million kWh per annum
Oxygen	NOK 2.50 per kg (range 2-2.5) 2,817 tonnes per annum (0.5 kg per kg of feed)

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[39] Investments required to establish a ground water source could vary widely depending on the sources of ground water available as well as on the type of soil or bedrock. Costs associated with maintaining the desired level of salinity in the water are assumed to be incorporated in the cost category labelled “other costs”.

	Oxygen storage tank rental: NOK 150,000 per annum (range 100-200,000)
Waste/wastewater	NOK 800 per tonne (range 130-2000). 8,380 tonnes per annum (1.5 kg per kg of feed, not dried)
Service, maintenance and repairs	NOK 3.5 million per year (range 3-4 million)
Office and administration	NOK 1.5 million
Other costs	NOK 10 million Includes laboratory, salinity, other chemicals, etc.
Fixed costs	
Management	Four managers

Sources:
Industry sources including equipment suppliers, smolt producers and potential/new entrants (full grow-out) for price and consumption of electricity and oxygen.
Equipment suppliers and industry sources for quantity and cost of sludge/waste disposal.
A combination of company sources and own judgement for service, maintenance and repairs and office and administration cost.

4.5 Cost of production

As described in chapter III, to analyse cost of production a steady state situation is assumed, meaning that the farm is fully operational (Asche & Bjørndal, op.cit). Among the benefits associated with land based aquaculture is the possibility of releasing batches of juveniles throughout the year so as to have harvestable fish all year around. As illustrated in the production plan, this example has a monthly release of 102,150 fry into the facility. The total amount of salmon harvested in one calendar year will be the same as the harvest from the 12 releases in a year (see appendix, table C1). Hence, annual costs and cost of production are estimated on the basis of 12 releases.

Table 4.4 specifies other operating costs per annum. These costs amount to NOK 9.70/kg, which is higher than the NOK 6.31/kg in traditional farming (chapter II, table 2.1). This may be explained by the difference in technology. Other operating costs include electricity, oxygen, bicarbonate (alkalinity), sludge/waste cost, service, maintenance and repairs, office and administration, and other annual operating costs (laboratory, salinity, other chemicals etc.).

Table 4.4 Other operating costs

	Unit	**Quantity**	**Price/ Unit**	**Steady state NOK ‘000**	**Per kg**
Electricity	4,000 kwh per tonne of production	20,484 kwh	1	20,484	4,1
Oxygen	0.5 tonnes per tonne of production	2,560 t	2,5	6,401	1,3
Oxygen - tank rental	annual cost (NOK ‘000)			150	0,0
Sludge/waste/wastewater	1.5 tonnes per tonne of feed	8074,7 t	800	6,460	1,3
Service, maintenance and repairs	annual cost (NOK ‘000)			3,500	0,7

Office and adm.	annual cost (NOK '000)	1,500	0,3
Other annual operating costs	annual cost (NOK '000)	10,000	2,0
Sum		**48,494**	**9,7**

In table 4.5, total annual cost of production in steady state is given as well as average cost per kg produced. Total production cost amounts to just over NOK 181 million. While variable costs represent 80 percent, fixed costs are 20 percent of the total. The most important components are feed, interest and depreciation on investments and other operating costs. Average cost of production per kg of salmon in "live weight" is NOK 36.3. To be comparable with official statistics, this must be converted to whole fish equivalents (WFE), using standard ratios (The Norwegian Directorate of Fisheries, 2016; See also table 4.5 below, comment c)). In WFE terms, the cost of production per kg of salmon is NOK 38.7.

Because of substantial working capital requirements, interest on working capital at 4% can constitute a considerable cost component and is therefore included as a variable cost.

Table 4.5: Cost of production

	Total cost NOK '000	**NOK/kg live weight**	**Percent of total (WFE)**	**NOK/kg WFE**
Variable:				
Feed	75 364	15,1	42 %	16,1
Roe (smolt)	1 362	0,3	1 %	0,3
Vaccines	2 071	0,4	1 %	0,4
Labour	10 640	2,1	6 %	2,3
Insurance fish	3,448	0.7	2 %	0,7
Other operating costs	48,494	9,7	27 %	10,3
Interest on working capital[a]	4,620	0,9	3 %	1,0
Sum variable costs	145 999	29.2	80 %	31,2
Fixed:				
Interest and depreciation on investments	30 867	6,2	17 %	6,6
Insurance on building and equipment[b]	604	0,1	0,3 %	0,1
Management	3 900	0,8	2 %	0,8
Sum fixed costs	**35 371**	***7,1***	20 %	7,5
Total production cost	**181,370**	***36,3***	100 %	38,7

a) Interest on working capital is on the basis of feed, roe, vaccines, labour, other operating costs, insurance and management costs.

b) Building is considered building, construction and project related costs, total NOK 206.6 million. Equipment and machinery is aquaculture system equipment, tanks and hardware, fish management, feeding and heating systems, vaccination and laboratory equipment, total NOK 192 million (table 4.1).

c) In accordance with NS 9417:2012 and the current practice of the Norwegian Directorate of Fisheries, the conversion factor from live weight to WFE is 1.067.

When compared to sea based farming (table 2.1, chapter II), it is noticeable that cost of production per kg is higher in the case of full cycle land based farming. It must, however, be noted that the numbers in this chapter are 2017 values as compared to 2015 values in table 2.1. Furthermore, interest on license values is not included in table 2.1 (as discussed in chapter II).

Comparing different cost categories, it can be noted that feed cost is slightly higher (NOK 14.40/kg as compared to NOK 13.18/kg) This is understandable, as the price of feed is assumed to be somewhat higher in land based aquaculture. In recirculating aquaculture systems, where nearly all of the water is filtered and reused repeatedly, feed quality including texture is particularly important for water quality. In terms of feed cost, it can also be noted that the fish in land based operations are grown and fed from the time of hatching, versus from a size of approximately 100 grams in the case of traditional sea-based grow-out operations. However, this difference in absolute feeding and growth of 100 g is not likely to make up a large part of the difference in feed cost per kg[40].

Land based aquaculture is also a technologically more advanced operation, which is reflected in the cost shares. Notably, interest and depreciation on facility and equipment constitute 17% of the total, amounting to NOK 31 million per annum (NOK 6.6/kg). This compares to NOK 3.97/kg or 14% of the total in sea based production (including own estimate for license values from the discussion in chapter II), with the difference being that in sea based production, license investments are the cost driver, while in land based production, investments in technology and facility drives the capital costs.

4.6 Net Present Value

For potential investors in a land based salmon farm, what is of interest is whether they will achieve an acceptable return on the capital invested. Evaluating the value of a company requires information about the cash flows it will generate. The objective for the investor is then to determine if the initial investment will provide a positive net present value (NPV) of cash flows given the investor's required rate of return (interest rate) as outlined in chapter III, see equation 4.1.

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[40] Assuming an economic FCR of 1, the feed quantity required to grow the smolts up to a size of 100 g is 100 g. Given a feed price of NOK 15 (smolt feed) and a harvest weight of 4.5-5 kg, the difference in feed cost due to the feeding of smolts should be roughly NOK 0.3-0.33/kg. Hence, the majority of the NOK 1.22 difference in feed cost seems to stem from difference in feed price or mortality assumptions rather than the difference in feeding period.

We can identify three types of cash flows in this case, namely those related to (i) investments and reinvestments, (ii) revenues from the sale of fish and (iii) operating costs such as feed and labour.[41] It is assumed that revenues are received in the same period as the fish is sold, while feed, labour and other inputs are paid in the period they are incurred. To carry out the analysis, information in previous sections will be used to determine the cash flows. The net present value analysis assumes that the production facility is delivered as a fully developed, turn-key facility in year 0 with investments of NOK 420 million. Moreover, all necessary permits, licenses and planning have been acquired. Hence, the first monthly purchase of roe may be scheduled for January 1st of year zero. After about two months in the hatchery, the first batch of 102,150 fry are released to feeding tanks on March 1st the same year. Following 18 full months of grow-out, the first batch of salmon is harvested in September of year one. It follows that from year two steady state production is reached, where salmon are released and harvested monthly, with an annual harvest of 5,000 tonnes.

In the estimation of net present value, we will assume that prices and costs remain at the same level, i.e., real prices remain unchanged. Assumptions about annual costs and revenues are summarised in table 4.6. The following operating costs are included: roe, feed, labour, vaccines, operating costs, management and facility investment. Financial costs – interest on fixed investments and working capital as well as depreciation – are not included, as the cost of capital is accounted for by including investments (and reinvestments) and the interest rate, representing the required return on capital. Moreover, depreciation does not involve any cash outlay.[42]

Table 4.6. Assumptions about costs and revenues years 0-2. Monetary values in NOK '000.

Assumptions:	Year 0	Year 1	Year 2 (steady state, as above)
Variable costs			
Roe	NOK 1,362	NOK 1,362	NOK 1,362
Feed quantity	*138.8 tonnes*	*3,495.6 tonnes*	*5,383,1 tonnes*
Feed costs	NOK 1,943.5	NOK 48,937.8	NOK 75,363,9
Number of man-years	*6*	*12*	*16*
Labour costs	NOK 3,990.0	NOK 7,980.0	NOK 10,640.0
Insurance fish	NOK 579.0	NOK 2,258.8	NOK 3,448.3
No of vaccines	*5 batches*	*12 batches*	*12 batches*
Vaccine cost	NOK 517.7	NOK 2,070.9	NOK 2,070.9

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[41] In principle, there can also be a terminal value of the investment.

[42] The situation would be different if taxes were included. This because depreciation influences taxable income and thus taxes paid.

Other operating costs	NOK 15,000.0	NOK 30,000.0	NOK 48,494.4
Fixed costs			
No of managers	2	4	4
Management costs	1,950.0	NOK 3,900.0	NOK 3,900.0
Insurance on facility and equipment	NOK 603.8	NOK 603.8	NOK 603.8
TOTAL COSTS	NOK 25,712.1	NOK 94,854.5	NOK 145,883.3
Price & revenue			
Salmon price	NOK 59/kg (HOG)[a], i.e., 49.2 (live weight)[b]		
Harvest quantity	0	4 batches, each of 416.8 tonnes	12 batches, 5,000 tonnes
Revenue	0	NOK 98,365	NOK 295,000

[a] The average forward contract price from March 2017 to December 2019, obtained from fishpool.eu per March 2017. The price is based on an index of fish sizes, premium quality and HOG weight

[b] As the production quantity is given in live weight, the price is converted to live weight in order to estimate corresponding revenues. A conversion rate from live to HOG of 1.2 is used, in line with NS and the Directorate of Fisheries. (This does not consider that processing costs are incurred between live and HOG weight. Consequently, the HOG price assumed here may not reflect the cost of processing).

Whereas full steady state cost of production is incurred from year two, the first two years of production see lower, yet increasing costs of production as biomass is built up and increasing amounts of capital are tied up in the fish stock. In terms of production workers, six are employed for 1st January year zero, another six are employed at the beginning of year one, while the full complement of 16 will be active from 1st January year to. Two managers are hired from the opening of the plant; the two additional ones on January 1st, year 1. Other operating costs increase over time to reach steady state. Feed costs are also considerably lower than in steady state while the biomass is being developed from scratch.

Total costs increase from NOK 25.71 million in year 0, to NOK 94.83 million in year 1 and to a steady state level of NOK 145.88 million in year 2. The increase is mainly due to feed, labour and other operating costs.

As for revenues, the first harvest of 416.8 tonnes occurs in December year one. As of year two, steady state harvesting takes place. When it comes to price, we need to use the expected price for the lifetime of the project. In view of historical fluctuations in price, this is, of course, impossible to assess. Initially, we will use NOK 49.20/kg, which is slightly less than the average forward price from March 2017 – December 2019 per February 2017, but notably still high from a historical perspective (Fishpool, 2017). For comparison, the average price between 2011-2017 (week 7) is NOK 41.30/kg. There are no revenues in year 0, NOK 98.368

million in year 1, and from year 2 onwards the steady state annual revenues represent NOK 295 million.

As such, annual cash flows over time from investments and reinvestments, revenues and costs are established. These are given in table 4.7.

As shown in table 4.1, while most equipment will have a lifespan of 20 years, some have a depreciation period of 10. For simplicity, we assume the production technology remains unchanged over time so that only a reinvestment of NOK 6 million is included.

Table 4.7. Annual cash flows: investments, revenues and costs. NOK million.

Year	Investment and reinvestment	Revenues	Costs
0	429.6	0	25.712
1		81.963	94.855
2		245.889	145.883
3		245.889	145.883
4		245.889	145.883
5		245.889	145.883
6		245.889	145.883
7		245.889	145.883
8		245.889	145.883
9	6.0	245.889	145.883
10		245.889	145.883
11		245.889	145.883
12		245.889	145.883
13		245.889	145.883
14		245.889	145.883
15		245.889	145.883
16		245.889	145.883
17		245.889	145.883
18		245.889	145.883
19		245.889	145.883
20: terminal value	669.621[a)]	6,147.225	3,647.075

a) This includes investments and reinvestments from year 20 to year 60. See appendix, table C3 for the investment and reinvestments used.

When valuing a company, there is a question as to the time period over which the investment should be considered. There is no definite answer to that question. We will choose two alternatives. The first is an investment horizon of 20 years[43]. This seems natural, as this

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[43] It might seem natural to include a terminal value for this case. The terminal value may be positive if land and machinery may be sold. It may also be negative, in case the owners need to pay more for the disposal of the facility than proceeds from sale of the land. As it is impossible to determine the value, we will disregard the terminal value.

is the lifespan of most of the technical equipment[44]. It is, however, also natural to consider an infinite time horizon. This is because if the initial investment turns out to be profitable, a reinvestment is likely after 20 years. For the infinite horizon case, we will assume this to be the case. This assumes that the production technology remains unchanged. This is, of course, a very strong assumption, but as reasonable as any other to be made.

For the case of an infinite time horizon, we have estimated the terminal value in year 20. For investments, this is the present value in year 20 of investments up to year 60 (appendix, table C3). Due to discounting, the setting of a cutoff year like often has a small impact on the terminal value. Revenues and costs are both constant in steady state so that the terminal value in year 20 is calculated according to the formula A/r, where A is the annual amount and r the rate of interest.

All values are discounted to year 0 according to the formula in chapter III (equation 4.1). Year 0 values are not discounted, year 1 values are discounted one year, etc. In doing so, it is assumed that all revenues and expenses are incurred on a linear basis throughout the year. This is not quite correct, as there is likely to be an uneven time profile for some of the outlays. Nevertheless, this simplification will have little impact on the result.

The results are given in table 4.8. With a 20-year horizon, the NPV is NOK 745.4 million while for the case of an infinite time horizon, it is NOK 1,580.8 million, more than a doubling. This is due to the rather large net terminal value. The IRRs are 17% and 19%, respectively.

All of these values indicate a very profitable investment. It must be noted that this assumes the farm runs smoothly from day one without any problems. In light of the development of the industry over time (chapter II) and in consideration of the fact that we are considering a new technology, this could be unreasonable. Nevertheless, while the industry has been growing rapidly for several decades, it has been very profitable for long periods of time, in particular recently.

Table 4.8. Net present value (NOK million) and internal rate of return.

	20 year horizon	Infinite horizon
NPV NOK million	745.4	1,580.8
IRR	17%	19%

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[44] King *et al.* (2016), in their study of alternative production models for Tasmania, estimate NPV for a 15-year timespan.

A number of simplifying assumptions have been made in the estimation of NPV and IRR, in particular that the price and cost of production remain constant over time. In view of the fact that both price and cost have been changing over time (chapter II), there is every reason to expect this to be the case also in the future. For this reason, we will undertake sensitivity analyses for changes in price and costs below. Moreover, we have assumed the technology remains unchanged over time. This is unrealistic, in particular, because we are considering a new technology that is largely untried in salmon farming. Thus, it is likely there will be many adjustments in technological solutions in the coming years.

It would be possible to include time trends for future developments in price and costs in addition to the discrete changes that will be considered in the sensitivity analyses below. This will not be done, as it appears very difficult to specify realistic time trends. Having said that, as producers master the new technology to a greater degree, this will represent improvements in technology and thus reductions in cost of production. This will make the investment even more profitable, which is likely to cause an increase in production that will have a dampening effect on price. The net effect of this is likely to be a reduction in profitability so that the NPV that has been presented here is likely to be overestimated.

It is noticeable that the NPV for an infinite horizon-project is almost twice that for a 20-year time horizon. As noted, there is great uncertainty about future prices and costs and more so, the longer the time horizon. For this reason, we will subsequently present results for a 20-year horizon only. This raises the question of a scrap value after 20 years. As discussed above, this can be positive or negative. The scrap value will here be set to zero, as it does not seem possible to set a meaningful value.[45]

4.7 Sensitivity analyses

As discussed not only here, but also in previous chapters, due to the dearth of empirical data there is great uncertainty as to the appropriate values of many important parameters included in this analysis. One way to address this issue is by use of sensitivity analysis (chapter III). With this approach, it is possible to identify the impact of uncertainty in a parameter on cost of production and NPV. Moreover, it is possible to vary several parameters at the same time so as to analyse their combined effect.

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[45] DnB Markets (2017) use a decommissioning cost/scrap value after 20 years of NOK – 30 million (based on a 10,000-tonne project), but there is no explanation as to how this value was arrived at.

4.7.1 Cost of production

We will now analyse how cost of production may vary with changes in important parameters and assumptions. The following parameters have been selected for sensitivity analyses:

1. Investments + 20 %.
2. Other operating costs + 20 %.
3. Monthly mortality + 20 %.
4. Late-cycle mortality: 20%
5. Growth – 20 %.
6. FCR +20%
7. Interest rate 8 %.

Essentially, all these changes are due to the introduction of a fairly new technology with only limited experience. 1) and 2) refer to uncertainty about investment as well as operating costs. 3), 4) and 5) refer to uncertainty about the biological production function. In principle, we could envisage two scenarios in the case of mortality and growth. In the first case, higher mortality or lower growth is anticipated so that this is corrected for by the purchase of more roe so that a 5,000-tonne production can be maintained. In the second scenario, which will be considered here, there is no such compensation causing a reduction in output of about 20% (in the two examples involving late-cycle mortality and reduced monthly growth). Results are presented in table 4.9. While both positive and negative changes are presented in table 4.9 and illustrated in figure 4.2, the following discussion is focused on the downside risk.

Table 4.9. Sensitivity analysis for cost of production– NOK/kg (WFE).

	-20 %	**Base case**	**20 %**
Investment	37,4 (-3%)	38,7	40,0 (+3%)
Other operating costs	36,5 (-3%)	38,7	40,9 (+6%)
FCR	35,0 (-10%)	38,7	42,4 (+10%)
Monthly mortality	37,9 (-2%)	38,7	39,5 (+2%)
Late-cycle mortality	-	38,7	46,7 (+21%)
Growth	42,2 (+9%)	38,7	36,3 (-6%)
Interest rate 8%:		Cost/kg =	42,3 (+9%)

With a 20% increase in investments, these now become NOK 515.5 million, resulting in higher interest and depreciation charges. Moreover, there will be a slight increase in insurance on building and equipment. The consequence of this is a 3.4% increase in cost of production to NOK 40.0/kg. A proportional increase of the same magnitude in other operating costs will cause an increase in cost of production of 5.7% to NOK 40.9/kg, a small part of which is attributable to an increase in working capital and thereby the consequences of a small increase in interest on working capital.

Regarding mortality, two scenarios are considered. In the first one, there is a 20% increase in monthly mortality throughout the lifespan of the fish[46]. This results in a decrease in the annual harvest quantity to 4,764.7 tonnes, with a 2% increase in cost of production to NOK 39.50/kg. It may be surprising the cost of production changes so little. The cost structure is characterised by large variable costs, and higher mortality implies a reduction in many of them (feed, vaccines, insurance and interest on working capital). Moreover, the increase by 20% is added to a low mortality rate in the first place – increasing from 0.5% to 0.6% of individuals per month of on-growing. During the period of higher mortality – the egg stage and initial start feeding month – relatively little cost has been accumulated per fish.

We also consider the consequence of late-cycle mortality. This kind of issue can occur as a consequence of early maturation or quality degradation of soon-to-be harvested fish. Such challenges have been of major concern throughout the production phase in existing land based operations and constitute an important part of the biological risk in this new type of biological environment. In this example, it is assumed that in month 16, 20% of the number of fish per generation die. This gives a new accumulated mortality of 29.3% from start feed to harvest, or 36.4% when the egg stage is included. Under this assumption, the annual harvest quantity becomes 4,021 tonnes. The consequence will be an increase in cost of production of 21% compared to the base case to NOK 46.7/kg.

The modified growth case involves a 20% lower fish weight compared to the base case in each month, starting from month one. Hence, in month 18, the batches are harvested at an average weight 20% less than the base case (3.7 kg vs 4.6 kg). In this case, the annual harvest becomes 4,000 tonnes, causing a 9% increase in cost of production to NOK 42.20/kg.

A modified feed conversion ratio is included because of the considerable share of feed in total costs – although the share is a bit lower than in sea based production. An increase in FCR by 20% is estimated to cause cost of production to increase to NOK 42.4/kg, an increase by 9.6%.

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[46] New mortality: hatchery: 10%*1.20 = 12%; month 0 (start feed): 4%*1.2 = 4,8%; all subsequent months of on-growing: 0.5%*1.2 = 0.6%. In total, the new accumulated mortality is 24.6%, compared to 20.9% before.

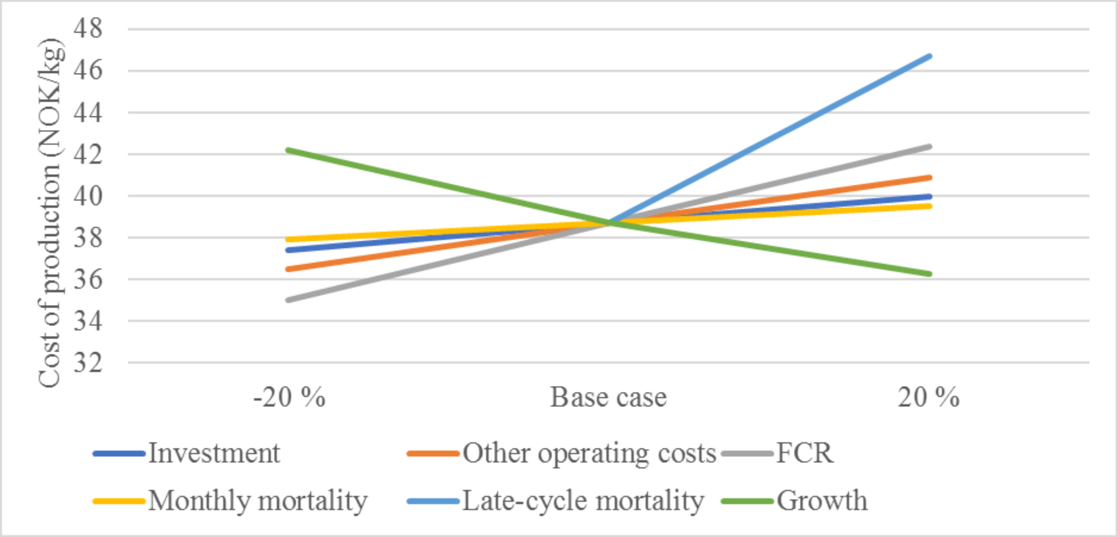

Figure 4.2: Sensitivity analysis for cost of production– NOK/kg (WFE).

A doubling of the interest rate has been specified due to the risk involved, despite the fact that we are looking at investments from society's point of view (cf. chapter III). In this scenario, we assume that the depreciation periods remain unchanged. With an interest rate of 8%, annual interest and depreciation charges increase from NOK 30.9 million (table 4.1) to NOK 43.4 million. As a consequence, cost of production per kg increases by 9.3% to NOK 42.3 (interest on working capital is also part of the change).

As underlined, we are talking about a new technology so that empirical data on cost of production are non-existent. Nevertheless, a number of engineering studies have been made. Table 4.10 summarises results from some of these studies. The specification of the cost structure is different from study to study, for example when it comes to inclusion of costs such as insurance and interest on working capital. We have therefore restated the cost components in terms of the categories that are found in all comparable studies.

Table 4.10. Estimates of cost of production in land based salmon farming. NOK/kg.

	Land based Norway, Iversen *et al.* (2013)[a)]	Land based low cost country, Iversen *et al.* (2013) [a)]	Liu *et al.* (2016) WFE[b)]	DNB (2017) WFE	This study WFE
Feed	9,8	9,8	11,8	13	16
Smolt (roe)	1,9	1,0	0,8	2	0.3
Salaries	2,4	1,2	3,3	3	3.1[c)]
Other operating costs	6,0	4,4	10,7	6	11.4[d)]
Depreciation and interest	8,5	6,2	7,6	6	6.6
Production cost total	**28,6**	**22,6**	**34,2**	**30,0**	**38.7**

a) It is not found whether this cost is based on live weight or WFE. However, the base case used for comparison in the study is the Norwegian Directorate of Fisheries’ statistics, which are given in WFE weight.
b) Liu *et al.* report cost per kg HOG. This cost has been converted to WFE-cost using a factor of 0,089 in accordance with the Norwegian Directorate of Fisheries and the Norwegian standard.
c) Includes wages (NOK 2.3/kg) and management (NOK 0.8/kg)
d) Includes interest on working capital (NOK 1.0/kg) and insurance (NOK 0.1/kg)

Cost of production per kg is highest in this study and lowest in Iversen *et al.* (2013). However, the latter is in 2013 values rather than 2017. Feed costs are considerably higher in this study than in all the others while smolt cost (roe in this study) are lower. Even if feed prices have been rising in recent years, the feed price in the current study is set quite high, based on information about the extra importance of feed and feed particles to water quality in recycling water systems[47]. Wage costs are comparable for four of the studies, while other operating costs are considerably higher in this study and Liu *et al.* (2016) than all the others. Depreciation and interest are also comparable in some of the studies.

4.7.2 NPV and IRR

To analyse senstitivity of NPV and IRR, we will consider the following scenarios:

1. Investments +/- 20 %
2. Other operating costs +/- 20 %
3. Total operating costs +/- 20%
4. FCR +/- 20%
5. Monthly mortality +/- 20 %
6. Late-cycle mortality +20%
7. Growth +/– 20 %
8. Price +/– 20%.

The first five are the same as for cost of production, however, we have also included a scenario analysing variation in price of 20%. This because there is much uncertainty about which price level can be expected in the future. Results are given in table 4.11.

Table 4.11. Sensitivity analyses NPV and IRR. 20-year lifespan.

	NPV			**IRR**		
	-20 %	**Base case**	**20 %**	**-20 %**	**Base case**	**20 %**
Investment	834 (+12%)	745	657 (-12%)	21 %	17 %	14 %
Other operating costs	866 (+16%)		624 (-16%)	19 %		15 %

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[47] The difference in feed costs may also be due to differences in variables such as mortality and FCR.

Monthly mortality	833 (+12%)	661 (-11%)	18 %	16 %
FCR	959 (+29%)	531 (-29%)	20 %	14 %
Total cost of prod.	1,124 (+51%)	367 (-51%)	23 %	11 %
Late-cycle mortality	-	210 (-72%)	-	8 %
Growth	412 (-45%)	1,079 (+45%)	12 %	22 %
Price	131 (-82%)	1,360 (+83%)	7 %	26 %
Interest rate 8%	NPV = 398 (47%)		IRR = 17 %	

A 20% reduction in growth and a concomitant reduction in output is seen to reduce NPV by about 45% compared to the base case, to NOK 412 million. A 20% reduction in price causes a decline in NPV by 82% to NOK 131 million and a reduction in IRR to 7% (new price is NOK 39.33/kg HOG). A recurring late-cycle mortality incident (without compensation in the number of fish released) cause a 72% decline in NPV. This assumes that the biological issue remains unresolved over time, and therefore, utilisation and fish density in the facility is lower.

The inclusion of a scenario with a higher interest rate is done simply to examine the consequence of raising the bar for an acceptable investment. That is, the cash flow remains unchanged but the interest rate applied to discount the cash flow is increased from 4% to 8%. This causes a reduction in NPV of 47%, decreasing to NOK 398 million (while the IRR is not affected). If the total cost of production increases by 20%, NPV is reduced by 51%.

Results are less sensitive to changes in the other parameters considered (figure 4.3). A 20% increase in any one of investments, other operating costs or monthly mortality all lead to a reduction in NPV of a magnitude between 11-16%. A 20% increase in FCR would cause NPV to decrease by 29% to NOK 959 million. Because of the larger share of feed cost in total cost of production, NPV is somewhat more sensitive to a change in FCR. However, not nearly as much as to those directly and significantly affecting sales, i.e., price and sales quantity, as illustrated in the late-cycle mortality, growth and price scenarios (see figure 4.3, illustrating the slope of the NPV curve for changes in each parameter).

It is interesting to note that the IRR for the case of investment + 20% is lower than those of increases in other operating costs and monthly mortality. This may have to do with different time profiles, in particular the fact that there are very large investments in year zero.

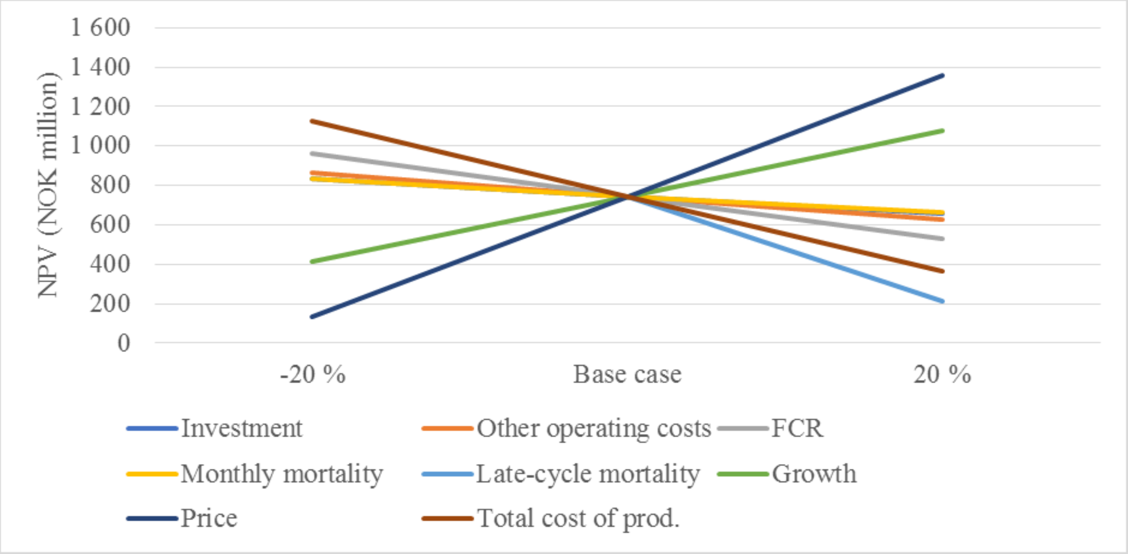

Figure 4.3: Sensitivity analyses NPV and IRR. 20-year lifespan.

4.8 Summary

This chapter has showed that land based aquaculture technology might offer an interesting and economically viable way of producing salmon. The NPV analysis suggests that there is potential for land based salmon aquaculture to be a profitable investment, but the results are highly dependent on price. When looking at farm gate cost of production before harvest, processing, transport and sales related costs, cost of production still looks likely to be higher in land based than in traditional farming – at least in the context of Norway. This means that the land based investor in a Norwegian context takes on considerable market risk – in addition to the biological and technological risk. Should the balance between supply and demand change in the future, that is a risk for the producers with the higher cost of production.

Nevertheless, due to the current mix of constrained supply, good market demand conditions, a favourable currency situation (in Norway) and cost related challenges in many traditional salmon producing countries, there may be a seldom opportunity in today's market for even relatively cost inefficient producers to thrive in the industry. Early entrants may also be expecting that as technology progresses and biology is increasingly well understood, production may be expanded, economies of scale and learning effects realised and cost of production come down.

The comparison with other studies also showed that the estimated cost of production in this study is relatively high – although the estimate made by Liu et al. (2016) based on a US. context is not very far below. The same study also found the environmental footprint of US produced land based salmon to be lower than sea based Norwegian salmon when sold in the

US market. Still, as underlined, with respect to the existing literature, the context as well as the cost structures are different from study to study. Equally important, we are talking about a new technology so that empirical data on cost of production are non-existent.

For this reason, it is acknowledged that adopting a stochastic methodology such as King *et al.* (2016) could have contributed an added value. Their study addresses the implications of economic risk on technology selection by incorporating stochastic variance in a comparative analysis of salmon grow-out production models by incorporating assumptions about the variability (range and distribution) of all inputs to the analysis. An important argument for doing this is to enable decision makers to develop an awareness of economic risk by visualising differences in variability of expected results. Without accounting for variance in investment appraisals managers might not make the most appropriate decisions[48] (King *et al.* 2016). The current analysis accounts for risk and uncertainty by undertaking sensitivity analysis for specific components in order to reveal specific risks and areas of importance. Although that is useful and contribute important managerial insights it does not reveal the variability profile for a project as a whole (which is of interest in a decision-making situation).

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[48] Even with such a stochastic analysis, however, the variability is still based on assumptions and distributions related to one specific point in time.

V. LAND BASED SALMON – POST SMOLT

5.1 Introduction

This chapter will analyse a land based post smolt operation. To examine the economic effects of prolonging the initial land based production phase, two different scenarios will be analysed, where the duration of the land based phase is varied. The base case will be analysis of production of 400-g smolts, but a smolt size of 600 grams will also be considered. The firm is assumed to be running its own hatchery, so that the salmon are grown on site from roe and up to the respective post smolt sizes. Subsequently, the fish are sold or transferred to a sea based aquaculture operation where they are released to sea-pens for grow-out up to a harvestable size of 5 kg.

As discussed in chapter II, the use of larger smolts in combination with sea-based grow-out is regarded as a way of lowering production risk by releasing more robust fish to sea and shortening the period of exposure to sea lice and diseases. Because of increased control of central production parameters such as temperature and light in the early stages of the salmon's life cycle, more optimal growth conditions can be maintained. Hence, as will be seen later, the use of post smolts should lead to a shorter overall production cycle as well as a shorter exposure time in sea. Moreover, this production model more closely resembles the traditional way of farming salmon, so that the technological and biological uncertainty ought to be lower than in the full land based grow-out scenario.

Investment, production plans and cost of production in land based smolt operations are analysed in the current chapter, before we later continue the analysis of the sea based operations in chapter VI. The distinction between land and sea is also helpful with respect to comparison of different smolt sizes and variation of the relative lengths of the sea based and land based production phase. In practice, the land based smolt phase and the sea based grow-out phase are completely separate operations. Both independent smolt producers and integrated companies are fairly common, although the trend seems to be towards integrated firms, controlling the entire production cycle from roe to harvest (Asche *et al.* 2013). Nevertheless, because of the close economic connection between smolt production and grow out, with many, if not most companies in the industry being vertically integrated (cf. chapter II), we will not undertake investment analyses of the separate operations but focus on cost of production.[49]

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[49] It would be possible to undertake investment analyses for integrated companies, however, that would go beyond the scope of this report.

As in the previous chapter, assumptions about economic and biological variables and parameters are based on information and meetings with the industry, farm representatives and research centres and will be presented in the following. The methodology is also the same as described in chapter III and applied in chapter IV.

The chapter is organised as follows: The base case with 400-g post smolt will be examined in chapter 5.2, followed by 600-g post smolt in chapter 5.3. The main focus is on 410-g smolts, whereas the analysis of 600-g smolts is simpler and centered on cost of production (per smolt). In smolt production, cost of production is often assessed at a per smolt basis. This is natural, as smolts are traditionally bought and sold at a price per fish rather than per kg.

Monetary values are in 2017 Norwegian kroner (NOK), unless otherwise notified.

5.2 Postsmolt 410 g

We will here consider a specific case of investment in a planned 1,600-tonne post smolt facility with annual production of 4 million smolts at an average individual size of 410 g. While we do not attempt to represent an average, it may be worthwhile to note that Norwegian smolt producing firms sold approximately 3.1 million individual smolts on average in 2015 (The Norwegian Directorate of Fisheries, 2017). Having said that, it must also be noted that because the average size of smolts delivered is unknown, it is difficult to evaluate the size or production capacity from these numbers. Nevertheless, as typical smolt size in recent years has been around 100 g, production capacity in traditional smolt production facilities is likely to be considerably less than what we will consider here.

When it comes to technology, it appears to be the case that despite a clear trend towards larger smolt and larger facilities with recirculation and reuse of water, the systems and concepts chosen are rather dissimilar. For instance, it may depend on access and availability of sources of water, such as sea water, ground water and fresh water as well as other infrastructure. According to industry sources, it could be assumed that investment in a smolt facility of this capacity – complete including a hatchery – would amount to NOK 30,000 per m^3 of production capacity, but because of variations in concepts and technology it is hard to compare and conclude (personal communication). Nevertheless, it can be noted that the investment per kg of production capacity varies with the size of smolts produced. According to one estimate, the investments per kg might be as high as NOK 4-500/kg of production capacity from roe and up to a size of about 100 g. Whereas this might decrease to about NOK 60-94/kg of production capacity for on-growing from 100 g to 500 g.

Our example is from a planned facility with four production departments and its own hatchery. The first departments are equipped with RAS technology using freshwater, while the latter departments with larger fish utilise RAS with saltwater for post smolt. In the first department, fish are held from 0.18 g to 50 g. In the second and third departments, the fish are grown from 50 to 200 g and in the last department, the fish grow from 200 to 400 g. It should be noted that the selection of technology, level of automation and water sources influence not only investment, but also biology (temperature, water conditions, growth and fish handling/stress) and cost of production (e.g. energy consumption, water treatment, labour and chemicals, etc.). Modelling such relations is beyond the scope of this report, which instead relies on assumptions that will be presented in the following sections.

5.2.1 Investments

As illustrated in table 5.1, total investments required to set up the facility is estimated at NOK 350.4 million, corresponding to NOK 219 per kg of annual smolt production capacity or NOK 88 per fish. The investments have been quality controlled by several industry representatives including equipment manufacturers.

The main cost components include the costs of building and construction and project related costs (NOK 170.9 million) and major aquaculture system equipment such as RAS, pipes, drains, filters and water treatment etc. (NOK 123 million). Other investments include tanks and tank equipment (NOK 20.5 million), various automation, surveillance and fish management equipment (NOK 12.1 million) and hatchery, waste and wastewater treatment, walkways and feeding system (NOK 18.9 million). The purchase of a 60,000 m^2 land plot is estimated at NOK 2 million[50]. Connection to road, water, electricity and plumbing is estimated to NOK 2 million, while other planning and application costs are set to NOK 1 million.

Table 5.1: Investments in a 1,600 tonnes postsmolt facility[a)]. NOK '000.

Investment	NOK ('000)	Economic lifetime	Depreciation and interest
Building, construction and project related costs	170,900	20	12,575.1
Aquaculture system equipment (RAS, pumping, piping, filter, water treatment & electric)	122,950	20	9,046.9
Production tanks, hardware and tank equipment	20,460	20	1,505.5
Various equipment (automation and surveillance, grading and fish handling, vaccination, cleaning system, ensilage and truck)	12,125	10	1,494.9
Hatchery, waste and wastewater treatment, walkways and feeding system	18,900	15	1,699.9

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[50] Land cost is likely to vary considerably from place to place depending on alternative uses of the land.

Infrastructure connection (road, water, electricity, plumbing)	2,000	-	80.0
Land/ building plot	2,000	-	80.0
Cost of planning, application, processing fee (state/ municipality) etc.	1,042	-	41.7
Total investment	**350,377**		**26,523.9**

As illustrated in the last column of table 5.1, the annual sum of interest and depreciation is estimated to NOK 26.5 million. Similar to the previous chapter, estimation of annual depreciation charges on the physical structures that depreciate over time is based on the annuity principle. The lifespan (amortisation period) of various components is assumed to vary from 10 to 20 years, while only interest is charged on investments which are assumed not to depreciate[51].

5.2.2 Production plan

The production plan for the smolt facility is quite similar to that presented before (chapter IV) in terms of the main parameters, but in this case with a much shorter production cycle since the fish are held on land only up to an average size of 410 g. In steady state, the facility receives four batches of roe per annum, releases four batches of fry to the production tanks and delivers four batches of post smolt to sea based grow-out operations. With the first batch of roe received in January, the second in April, the third in July and the fourth and last batch in October, the production plan for one batch and for the first year of operations are shown in table 5.2 a and b, respectively. As illustrated, only one delivery of post smolt to sea is made in year zero. However, the operations reach full steady state production with four annual deliveries starting already from year one.

As shown below (table 5.2a, second column), the smolt facility has four departments. The operations are organised according to an “all inn, all out” principle, meaning that the batches of fish remain completely separated from each other throughout the production cycle. Before the release of a new batch into a department, it is emptied of fish and cleaned. This reduces the risk of major disease breakouts and transfer of diseases between the generations of fish. As each batch of fish is held in each department for the same period of time and the operations follow the same pattern of releases and deliveries, these routines can be maintained effectively over time. The growth data are the same as presented under general assumptions in chapter IV.

Table 5.2a: Production plan for one batch

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[51] Amortisation factors are 0,07358 for 20 years, 0,08994 for 15 years and 0,12329 for 10 years.

Month (beginning)	Department[a)]	Weight (g) per fish, w_t	Weight (g) increase, $w_{t+1} - w_t$	Survival %	Number of fish
0	1	0,2	0,6	0,960	1 084 287
1	1	0,8	2,3	0,995	1 040 915
2	1	3,1	4,9	0,995	1 035 711
3	2	8,0	16,0	0,995	1 030 532
4	2	24,0	26,0	0,995	1 025 379
5	2	50,0	42,0	0,995	1 020 253
6	3	92,0	73,1	0,995	1 015 151
7	3	165,1	104,2	0,995	1 010 076
8	4	269,4	140,9	0,995	1 005 025
9	4	410,2			1 000 000

a) Fish are held in each department for an equally long time in order to utilise the facility. This cannot be reflected in the monthly numbers.

Table 5.2b: Production plan first year:

	Batch 1	Batch 2	Batch 3	Batch 4
01.jan	Roe			
01.feb				
01.mar	0,2			
01.apr	0,8	Roe		
01.mai	3,1			
01.jun	8,0	0,2		
01.jul	24,0	0,8	Roe	
01.aug	50,0	3,1		
01.sep	92,0	8,0	0,2	
01.okt	165,1	24,0	0,8	Roe
01.nov	269,4	50,0	3,1	
01.des	410,2	92,0	8,0	0,2

The main parameters of the production plan are summarised in table 5.3. As mentioned, each delivery of post smolts to sea consists of 1 million fish at an average size of 410 g. Because of mortality, a quantity of 1,204,763 eggs are needed per batch in order to grow 1 million of post smolts ready for delivery. After about two months in the hatchery, 0.18-gram fry are released to start feed. The grow-out period from start feed up to post smolts of about 410 g is about 11 months.

Table 5.3: Production plan

Annual production	4 million post smolts per year, each of 410 grams. Total land based production capacity equivalent to 1,600 tonnes
Annual quantity of roe	Four batches, each of 1,210,817 eggs
Production period	Hatchery: 6-10 weeks from egg delivery to start feed (0.2 g)
	Smolt: About 10 months from 0.2 g fry to post smolts of an average weight of 410 g

Number of fry/postsmolt for delivery	Four deliveries to sea per year; 1,000 000 fish per delivery
Mortality	Hatchery: 10 %
	Smolt: 4% mortality in the initial month after release of 0.2 g fry to start feed. Subsequently 0,5% per month up to the average weight of 410 g[a]
Price of roe	NOK 1.00 (range 1.00 - 1.60 depending on breed)
Vaccines	NOK 1.8 (range 1.5-2 per vaccine depending on contents) (NOK 2.80[b)] per smolt incl. labour cost)
Biological feed conversion ratio (FCR)	0.9
Annual feed quantity:	1,494,857
Feed price	NOK 15 per kg (range NOK 13-17 depending on contents)

a) This number includes the mortality resulting from the practice of sorting out smaller and weaker fish.

Sources: EWA consulting and other industry sources for the price of feed and vaccines and for mortality assumptions. As before, growth estimates are obtained from industry sources (0.2 g – 95 g) and Nofima (95 g +). As in chapter IV, the biological FCR for fish up to 800 g is 0.9. Mortality hatchery and smolts: Company sources in smolt production and publicly available information from applications for Norwegian smolt production permissions.

As the firm receives its first delivery of roe in January of year 0, the first batch of 1,084,287 fry are released to start feed in the month of March (table 5.2b). Natural mortality is set to 4% in the first start feeding month and subsequently 0,5% per month until the fish reach the average size of 410 g and are transferred to sea. Mortality is assumed to occur at the end of the month, so that given this production plan and the given feed conversion ratio (0,9), annual feed quantity is estimated to 1,495 tonnes (see appendix, table C2). With a feed price of NOK 15 per kg, this gives an annual feed cost of NOK 22.42 million. Vaccination is assumed to occur late in month 5, when the weight of the fish is about 80 g. The average number of fish in the month is 1,017,702.

Assumptions about costs are given in table 5.4. The required number of full-time production workers is estimated to six, including hatchery and production department. Given annual wages of NOK 665,000 including social costs, annual labour costs amount to NOK 3.99 million. As before, other operating costs include electricity, water, maintenance, oxygen, sludge/waste cost, vaccination and other (equipment for office, laboratory, etc.). Fresh water is assumed to be used mainly in the initial part of the production cycle, whereas the latter production phases are based on saltwater (sea water) and the cost of water mainly consists of energy cost.

Table 5.4: Cost assumptions:

Variable costs	
Number of man-years	6
Electricity	NOK 1 per kwh. (including “network rental fee” and “electricity fee” 9.6 million kWh per annum
Oxygen	NOK 2.50 per kg. 800 tonnes per annum (0.5 kg per kg of production) Oxygen storage tank rental: NOK 100-200,000 per annum
Water	0,4 m^3 fresh water per minute. NOK 1.5 million per year
Waste/wastewater	NOK 130-800-2000 per tonne. 2 724.5 tonnes per annum (1.5 kg per kg of feed, not dried)
Service, maintenance and repairs	NOK 1.5 million per annum; range 1-2 million
Office & administration	NOK 1,000,000
Other costs	NOK 3,200,000
Insurance fish	NOK 1,482,000
Fixed costs	
Management	Three managers

5.2.3 Cost of production

Again, the analysis in steady state is based on one year’s release of fish – assuming that the growth and mortality assumptions as well as the pattern of releasing and delivering fish remain unchanged over time. Hence, the total delivery of post smolts in one calendar year will be the same as the sum of smolts delivered from all releases in a year. Before presenting cost of production, we specify other operating costs. As shown in table 5.5, other operating costs are quite similar to those from chapter IV and include electricity, oxygen, sludge/waste cost, service, maintenance and repairs, office and administration, and other annual operating costs (laboratory, salinity, other chemicals etc.). Other operating costs are estimated at NOK 20.7 million per year or NOK 5.20 per smolt produced.

Table 5.5: Other operating costs

	Unit	**Quantity**	**Price**	**Steady state NOK ‘000**	**Per smolt**
Electricity	6 kWh per kg of production	9,600,000	1	9,600	2.4
Oxygen	0.5 kg per kg of production	800,000	2,5	2,000	0,5
Oxygen - tank rental	annual cost			150	
Water (fresh water)	0,4 m3 per minute	210,240	7	1,472	0,4
Sludge/waste/wastewater	1.5 tonnes per tonne of feed	2,681.9	800	2,145	0,5
Service, maintenance and repairs	Annual cost			1,500	0,4
Office and adm	Annual cost			1,000	0,3
Other costs	Annual cost			3,200	0,8
Sum other costs				20,716	5.2

Total annual cost in steady state will be NOK 91.9 million with an average cost per 410-g smolt of NOK 23.00, which compares to NOK 10.38 for a 100-g smolt (see table 5.6 for comparison). Variable costs and fixed costs represent 67% and 23% of the total, respectively. The largest cost component is interest and depreciation (29%) followed by feed (24%) and other operating costs (23%).

Table 5.6. Cost of production for an annual production capacity of 4 million smolts. Total annual production costs and cost of production per kg & per post smolt. Monetary values in NOK.

	410-g smolt			**100-g smolt (2015)**	
	Total cost ('000)	**Cost per fish (NOK/fish)**	**Percent of total**	**Cost per fish (NOK/fish)**	**Percent of total**
Feed	22,423	5,6	24%	1.50	14%
Roe	4,819	1,2	5%	1.73	17%
Vaccines	7,327	1,8	8%	1.16	11%
Labour	3,990	1,0	4%	1.66	16%
Insurance fish[a)]	1,482	0.4	2%	0.10	1%
Other operating costs	20,716	5.2	23%	2.80	27%
Interest on working capital[b)]	1,177	0.3	1%		
Sum variable costs	61,934	15.5	67 %	8.95	86%
Interest and Depreciation	26,524	6.6	29%	1.41	14%
Insurance on building and equipment[c)]	539	0,1	1%		
Management	2,925	0,7	3%		
Sum fixed costs	29,988	7.5	33 %	1.41	14%
Total production cost	**91,922**	**23.0**	**100%**	**10,38**	**100%**

a) Insurance premium on fish is estimated over an annual, steady state production period on the basis of all variable costs incurred in order to raise the fish (roe, feed, vaccines, labour and other operating costs).

b) Working capital is estimated for an 11-month production period. It is assumed that all costs (feed, roe, vaccines, labour, other operating costs, insurance fish, building and equipment and management) are incurred in a linear fashion over time.

c) Insurance is estimated based on a building cost of NOK 170.9 million with other equipment (aquaculture system, production tanks, various equipment, hatchery, waste and feeding systems) amounting to NOK 174.435 million.

Source for cost of production of 100-g smolts: The Directorate of Fisheries.

There is a major difference in the cost structures for 100-g and 400-g smolts when it comes to variable and fixed costs. In the post smolt case, fixed costs constitute as much as 33% compared to 14% for the 100-g case. This difference is a consequence of large investments for the post smolt facility, giving rise to high annual interest and depreciation charges. Considering the official statistics which make up the 100-g case, explanations of the difference in capital costs may include older facilities and equipment that has already have been depreciated. This compares with our base case scenario which assumes the use of the most modern equipment and building standards available[52]. Companies' financial structure may be relevant as well.

The next major cost item is feed, constituting 24% of production cost. The increase in feed cost per fish needs little explanation as the fish are now raised to 410 g rather than just 100 g. Vaccines are also a major cost item, constituting 8% of the total cost – or 11% in the case of 100-g smolts[53]. Labour, insurance and management contribute relatively moderate to the cost of production in our example, amounting to 4%, 0.5% and 3%, each. The share of labour cost is much higher in the official statistics, at 16% of the total. However, this probably includes management and perhaps other staff. Other operating costs are considerable in both cases, amounting to 23% and 27%, respectively. It can be noted that feed, vaccines and operating costs are higher for 410-g smolts. However, the relative increase is far less than the relative increase in size from 100 to 410 g (not relevant in terms of vaccines). Moreover, despite higher fixed costs, the cost per gram produced is much lower for the 410-g post smolt than for the 100-g[54].

5.2.4 Net present value

Assumptions about the delivery of a fully developed, turn-key facility in year 0 remains the same as before. It is assumed that the facility is delivered in January of year 0, with the first delivery of roe scheduled for the same month. With a production cycle that lasts until the fish reach a size of 400 g, it takes only one year of building up operations before full production is reached. Cost assumptions for the first year of less than full production is outlined in table 5.7,

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[52] Building standards have become a lot more demanding in recent years, according to industry sources.

[53] It is interesting to note that since the mortality is low in the few months after vaccination, the cost of vaccination per smolt is almost equal to the price per vaccine. Recalling that the price range is 1.5-2 per vaccine, a meaningful saving can be made by using a cheaper vaccine. If smolts tend to be sold as "vaccinated smolts" without further specification and opportunities for control, this may give rise to incentives of "moral hazard" and selection of a less-than-optimal vaccination strategy. This analysis has not looked into the market for smolts and assume that producers are concerned with keeping the fish as healthy as possible, but as mentioned in chapter II, many salmon farming companies have integrated into smolt production, aiming to take control of their own supply and of smolt quality.

[54] Nevertheless, the most relevant comparison of cost per gram produced between smolt and post smolt after the fish reach a size of 100 g may be the production cost per gram after transfer to sea. Nevertheless, it is worthwhile to note this indication of declining cost per kg of production of smolt and post smolt on land.

presented together with a repetition of the steady state cost of production from year two and onwards, which was estimated above.

As illustrated, feed costs are considerably lower than in steady state while the biomass is being developed from scratch, amounting to somewhat more than a third of the feed quantity in full production (table 5.7). We assume that at start-up, four workers and two managers are employed with a full staff complement from January 1st, Year 1.

Table 5.7: Cost of production assumptions for the first and second year of land based post smolt operations. Cost in NOK '000 (except smolt price).

Assumptions:	Year 0	Year 1 (steady state, as above)
Variable costs		
Roe	NOK 4,819	NOK 4,819
Feed quantity	548 tonnes	1,495 tonnes
Feed costs	NOK 8,221	NOK 22,423
Number of man-years	4	6
Labour costs	NOK 2,660	NOK 3,990
Insurance fish	NOK 759	NOK 1,482
Number of vaccines	2 batches	4 batches
Vaccine cost	3,664	NOK 7,327
Other operating costs	NOK 11,000	NOK 20,716
Fixed costs		
No of managers	2	3
Management costs	NOK 1,950	NOK 2,925
Insurance on facility and equipment	NOK 539	NOK 539
TOTAL COSTS	NOK 33,611	NOK 64,220
Price & revenue		
Smolt price 400 g	NOK 30 per fish	NOK 30 per fish
Revenue	NOK 30,000	NOK 120,000

Price should be based on expected price over the lifetime of the investment. Most smolt is nowadays transacted in vertically integrated companies so that transfer prices are relevant. Some smolts are also sold in the open market, however prices are not as readily available as for salmon. We have used information from two industry sources and own judgement to set the price of NOK 30 per smolt.[55]

A summary of the cash flows from the post smolt operations are given in table 5.8; investments, reinvestments and costs of production (only cash flows, not depreciation and

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[55] First reference: Price is NOK 12 for 100-gram smolts + NOK 0.05-0.07 per additional gram – fully vaccinated. Ref: Contact from Aller Aqua Norway AS. Second reference: Total cost of production per smolt about NOK 10-11 kr per 100 g smolt + about NOK 0.05 per additional gram (Ref: a smolt producing firm).

interest on capital) are given in table. For reasons explained in chapter IV, only a 20-year horizon will be considered.

Table 5.8: Cash flow from land based post smolt operations. Year 0-20.

Year	**Investment and reinvestment**	**Revenue**	**Costs**
0	350,377	30,000	33,611
1		120,000	64,220
2		120,000	64,220
3		120,000	64,220
4		120,000	64,220
5		120,000	64,220
6		120,000	64,220
7		120,000	64,220
8		120,000	64,220
9	12,125	120,000	64,220
10		120,000	64,220
11		120,000	64,220
12		120,000	64,220
13		120,000	64,220
14	18,900	120,000	64,220
15		120,000	64,220
16		120,000	64,220
17		120,000	64,220
18		120,000	64,220
19		120,000	64,220

As shown in table 5.9, the NPV of the investment amounts to NOK 359 million with an IRR of 14%. This indicates a profitable investment. Nevertheless, the IRR is considerably lower than for the land based facility.

Table 5.9 Net present value (NOK '000) and internal rate of return.

	20-year horizon
NPV	NOK 359.195 million
IRR	14%

5.2.5 Sensitivity analyses

While there is much experience with the production of 100-g smolts, experience with post smolt on land is still limited although increasing. Even if production uncertainty is far less than for full cycle land based production, sensitivity analyses will be conducted.

Cost of production

We will now analyse how cost of production may vary with changes in important parameters and assumptions. The following parameters have been selected for sensitivity analyses:

1. Investments +/- 20 %.
2. Other operating costs +/- 20 %.
3. FCR +/- 20%
4. Monthly mortality +/- 20 %.
5. Interest rate 8 %.

Uncertainties are related to selection of technology and the associated level of investments as well as to cost of production and the biological needs of smolts of this size on land. 1) and 2) refer to uncertainty about investment as well as operating costs. We consider both positive and negative changes, although as opposed to the land based grow-out facility, the smolt facility may be more at the mid or high range of the investment scale according to today's situation. In contrast to full grow-out, the cost share of feed relative to other cost categories is not so dominant. Nevertheless, sensitivity analysis is conducted for FCR also here, while 4) refers to uncertainty about the biological production function. Results are given in table 5.10. Both positive and negative changes are illustrated, while the discussion focuses mostly on downside risk.

Table 5.10. Sensitivity analysis for cost of production per smolt – NOK/stk

	-20 %	**Base case**	**20 %**
Investment	21,7 (-6%)	23,0	24,3 (+6%)
Other operating costs	21,9 (-5%)	23,0	24,1 (+5%)
FCR	21,7 (-6%)	23,0	24,2 (+5%)
Mortality	22,4 (-3%)	23,0	23,6 (+3%)
Interest rate 8%:		Cost/smolt =	25,8 (+12%)

Overall there is limited sensitivity to the changes in cost of production caused by the parameters considered. A +/- 20% change in investments changes cost of production by only 6%. Even a doubling of the interest rate only causes cost of production to increase by 12%. As illustrated in figure 5.1, the impact of changes in the specified parameters are of relatively similar magnitude.

The modified monthly mortality rate is the change with the least effect. However, this is much because the mortality rate is very low in the first place, while the major mortality happens early in the production cycle. A substantial share of cost of production – such as feed costs – are variable, causing the annual cost to be reduced when more fish die and less is produced. The positive mirror image of increased mortality is a mortality reduction. In both cases, compensation in the number of fish released is not undertaken – so that either the facility is constantly underutilised, (and slightly less fish sold) or contrary that a higher density can be maintained with the same level of water quality and welfare (and slightly more fish sold).

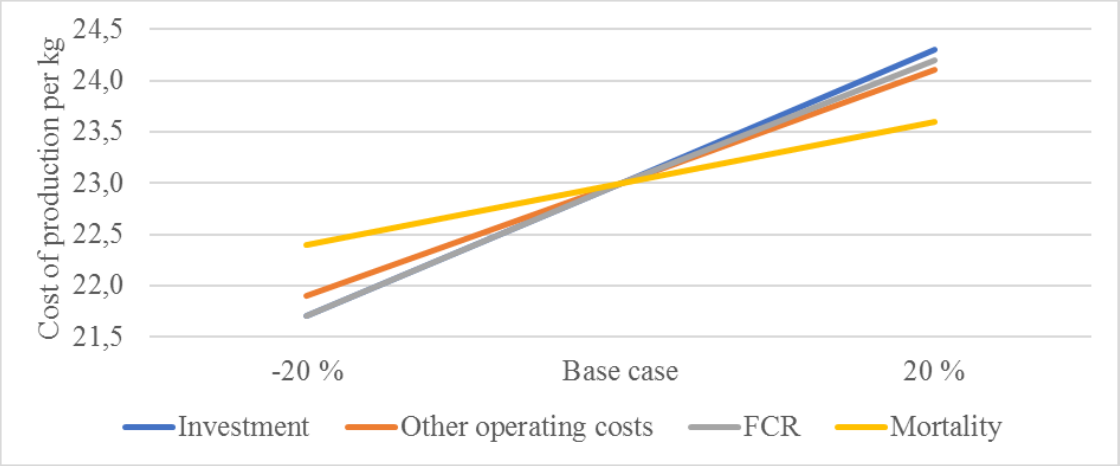

Figure 5.1: Sensitivity analysis for cost of production per smolt – NOK/fish.

NPV and IRR

To analyse senstitivity of NPV and IRR, we will consider the following scenarios:

1. Investments +/- 20%
2. Other operating costs +/- 20 %.
3. FCR +/- 20%
4. Mortality +/- 20 %.
5. Price +/– 20%.
6. Interest rate 8%

The results are presented in table 5.11. Most scenarios suggest a fairly profitable investment. The NPV is moderately sensitive to changes in investment and other operating costs as well as mortality. A 20% change in each of the three parametres other operating costs, FCR and monthly mortality each cause NPV to vary by between 13-19%. The impact of a 20% change to investment is of a bit larger magnitude, causing NPV to change by 21%. This probably has to do both with the time profile of cash flows and the size of investments. The major attention, however, goes to the considerable sensitivity of NPV to changes in price.

Table 5.11. Sensitivity analyses NPV and IRR. 20-year lifespan.

	NPV			**IRR**		
	-20 %	**Base case**	**20 %**	**-20 %**	**Base case**	**20 %**
Investment	433,1 (+21%)	359,2	285,2 (-21%)	19 %	14 %	11 %

Other operating costs	417,2 (+16%)	359,2	301,2 (-16%)	16 %	14 %	13 %
FCR	426,0 (+19%)	359,2	292,3 (-19%)	16 %	14 %	13 %
Mortality	406,1 (+13%)	359,2	313,4 (-13%)	15 %	14 %	13 %
Price	38,0 (-89%)	359,2	680,4 (+89%)	5 %	14 %	22 %
Interest rate 8%		NPV =	169,2 (-53%)	IRR =	14 %	

Figure 5.2 illustrate the considerable dependence of the results on price assumptions. As read from table, a 20% change in smolt price causes NPV to change by as much as 89%.

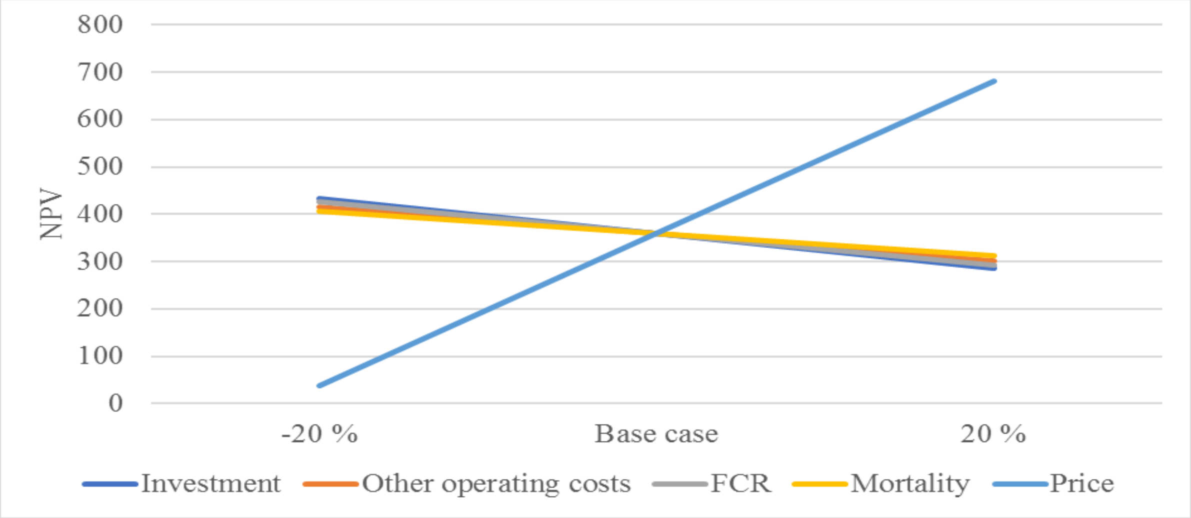

Figure 5.2: Sensitivity analyses NPV and IRR. 20-year lifespan.

5.3 Postsmolt 600 g

This section will consider a further extension of the land based post smolt phase, taking the fish up to a size of about 600 g before release to sea. The starting point of the analysis is the same facility and production plan as analysed in chapter 5.2, but with investment in an additional production department where the post smolts grow from 400 g and up to 600 g. This amounts to an extra annual production capacity of about 800 tonnes, increasing the annual production from the previous 1,600 tonnes to 2,360 tonnes.

The analysis is based on the same methodology as for 410-g post smolts, but the presentation will be simplified. As before, the focus is on cost of production.

5.3.1 Investment

The investment required to set up an additional department for production of 600-g smolts[56] is estimated to NOK 70 million (table 5.12). This corresponds to investment of NOK 87.5 per kg of incremental production capacity. This is lower than the initial investments, for a capacity up

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[56] The predicted weight on the day of the scheduled release to sea (the first day of the month) is 593 grams, as presented in the production plan. In the text, this is rounded up to 600 g.

to 1,600 tonnes, indicating the possible existence of economies of scale. The investment is based on a department consisting of three additional production tanks, each with a diameter of 16 m and based on a fish density of 70 kg per m^3. It must be added that in practice, the division into departments would have to be adapted for the production facility as a whole. This is due to retention times within each department; these must be similar to secure flow and capacity utilisation of the facility as a whole[57].

With the added extension of the facility, total investments are up from NOK 350.4 million in the 400-g base case to NOK 420.4 million based on 600-g post smolt. Annual depreciation and interest are now NOK 31.7 million (table 5.12). With the increased annual production capacity, investment amounts to NOK 175.2 per kg of annual smolt production capacity or NOK 105.6 per fish. This compares to NOK 219 per kg of annual smolt production capacity or NOK 88 per fish in the 400-g base case.

Table 5.12: Investments in a 1,600 tonnes postsmolt facility. NOK '000.

Investment	NOK ('000)	Economic lifetime	Depreciation and interest
Total investment, base case (410 g)	350,377		26,523.9
600-g department	70,000	20	5,151.7
Total investment, 600-g production facility	**420,377**		**31,674.7**

5.3.2 Production plan

The production plan for the 600-g case is precisely the same as for 410-g smolts up to the point of release to sea. However, in this case the fish are held for an additional month in the new department upon reaching a size of 410 g, instead of being released to sea (see table 5.13). Thus, only the last row of the production plan for a batch of smolts need to be changed. As the table shows, the number of fish delivered to sea is slightly reduced as a consequence of an additional month of mortality.

Table 5.13: Production plan for one batch

Month (beginning)	Department	Weight (g) per fish, w_t	Weight (g) increase, $w_{t+1} - w_t$	Survival %	Number of fish, Nt
0	1	0,2	0,6	0,960	1 084 287
1	1	0,8	2,3	0,995	1 040 915

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[57] Otherwise, the fish would stay only for a very short time in the last department, so that this part of the facility would be empty much of the time. This is not realistic, so in practice the division into departments would be different. Alternatively, the last department could be designed to keep the fish up to a larger size – for on-growing for the same time period as it takes for the next batch of fish to be ready to be released into the department.

2	1	3,1	4,9	0,995	1 035 711
3	2	8,0	16,0	0,995	1 030 532
4	2	24	26,0	0,995	1 025 379
5	2	50	42,0	0,995	1 020 253
6	3	92	73,1	0,995	1 015 151
7	3	165	104,2	0,995	1 010 076
8	4	269	140,9	0,995	1 005 025
9	4	410	183	0,995	1 000 000
10	5	593			995 000

A production plan is given in table 5.14 with cost assumptions in table 5.15. The tables illustrate changes and adjustments to the ones above for 410-g smolts. Assumptions that are left out from the tables remain as before.

Table 5.14: Production plan

Annual production	3.98 million post smolts per year, each of 593 grams. Total land based production capacity equivalent to 2,360 tonnes
Number of fry/post smolt for delivery	Four deliveries to sea per year; 995,000 fish per delivery
Annual feed quantity:	2,153,555
Feed price	NOK 15 per kg (range NOK 13-17 depending on contents)

Table 5.15: Cost assumptions:

Variable costs		**Change**
Number of man-years	7	+1
Electricity	NOK 1 per kwh. (including “network rental fee” and “electricity fee”. 6 kwh per kg of production 14.4 million kWh per annum	
Oxygen	NOK 2.50 per kg. 1,200 tonnes per annum (0.5 kg per kg of production) Oxygen storage tank rental: NOK 100-200 000 per annum	
Water	0,4 m^3 fresh water per minute. NOK 1.5 million per year[a)]	
Waste/wastewater	NOK 800 per tonne (range NOK 130-2,000). 3,230 tonnes per annum (1.5 kg per kg of feed, not dried)	
Service, maintenance and repairs	NOK 2 million per annum; range 1-2 million	+0.5 mill.
Other costs	NOK 4 million	+0.8 mill.

a) The consumption of fresh water is left unchanged. The selection of water sources and related costs are as mentioned not straightforward. In this case, it is assumed that the facility has both a freshwater and a seawater source, with freshwater primarily in the initial phases (<80-100 g). After that, salt water is the dominant water source, so that the cost of water consists primarily of energy costs.

5.3.3 Cost of production

In table 5.16 we present total annual cost for the 600-g smolt production, assuming steady state. We also give average cost of productionper smolt and, for comparison, also for 410-g smolt.

The cost structures are fairly similar, but variable costs (70%) represent a slightly higher share than before at the expense of a slightly lower cost share for fixed costs (30%).

Table 5.16. Cost of production for an annual production capacity of 4 million post smolts. Cost of production per fish. NOK.

		600-g smolt		410-g smolt	
	Total cost	NOK/ fish	% of total	NOK/ fish	% of total
Feed	32 303	8,1	28 %	5,6	24%
Roe	4 819	1,2	4 %	1,2	5%
Vaccines	7 327	1,8	6 %	1,8	8%
Labour	4 655	1,2	4 %	1,0	4%
Insurance fish[a)]	1 943	0,5	2 %	0.4	2%
Other operating costs	28 606	7,2	25 %	5.2	23%
Interest on working capital[b)]	1 526	0,4	1 %	0.3	1%
Sum variable costs	81 179	20,4	70 %	15.5	67 %
Interest and Depreciation	31 675	8,0	27 %	6.6	29%
Insurance on building and equipment[c)]	647	0,2	1 %	0,1	1%
Management	2 925	0,7	3 %	0,7	3%
Sum fixed costs	35 247	8,9	30 %	7.5	33 %
Total production cost	**116 426**	**29,3**	**100 %**	**23.0**	**100%**
Production cost per g		**0.049**		**0.056**	

a) Insurance premium on fish is estimated over an annual, steady state production period on the basis of all variable costs incurred in order to raise the fish (roe, feed, vaccines, labour and other operating costs).
d) Interest on working capital is, as before, estimated based on feed, roe, vaccines, labour, other operating costs, insurance and management costs.
b) For simplicity, it is assumed that half of the investment in the 600-g department is related to building and half to equipment in the calculation of insurance cost.

Cost of production for a 600-g smolt is NOK 29.30 compared to NOK 23.00 for a 410-g smolt, i.e., a difference of NOK 6.30, or 27.4% higher. This is mainly due to higher feed costs (NOK 2.50), operating costs (NOK 2.00) and interest and depreciation (NOK 1.40) per fish. Notwithstanding the increase in weight per fish, the production in terms of number of fish is not increased in this case. So, when cost and investment increase, so does the cost of production per fish.

5.4 Summary

This chapter has indicated that investments in production of post smolt may be a profitable investment and that economies of scale might exist in larger post smolt facilities. In terms of cost of production, it is estimated that the cost of a 410-g post smolt could amount to about

NOK 23 per fish. This corresponds to a cost of production per kg of NOK 56. Although there are few references readily available for comparison, information is available on the estimated cost of production for a 419-g smolt for a company in the Faroe Islands in 2013/14, which was NOK 19.95 per fish, corresponding to NOK 47.6 per kg (in 2013/14 prices) (Kverneland, 2016).

The cost of a 600-g smolt in the current analysis is estimated to NOK 29.3, which would correspond to a cost of production of 49.4/kg. Berget (2016) estimated cost of production per kg for 650-g smolts to NOK 49.15/kg, which would be equivalent to 31.9 per fish. The similarities between these few estimates and those of the current study are almost surprising given the uncertainty associated with the data. Berget (2016) also estimated cost of production of 1-kg post smolt, at NOK 42.6 per kg and per fish.

Table 5.17: Comparison of estimated cost of production from other studies and sources and the current study. 400-g, 600-g, and 1,000-g smolts.

	400-g		**600-g**		**1,000-g**
	Per fish	**Per kg**	**Per fish**	**Per kg**	**Per fish**
This study	23.0	56.0	29.3	49.4	-
Berget (2016)	-	-	29.4[a)]	49.2	42.6
Industry source	26.5	64.6	36.0	60	56
Hiddenfjord 2013/14	19.95[b)]	47.6	-	-	-

a) Based on the cost of production per gram of a 650-g smolt – transformed to 600-g (by dividing by 650 and multiplying by 600).

b) 419-g smolt in 2013/14.

As noted, approximate estimates have also been obtained from industry sources – indicating own production costs around NOK 11 for a 100-g smolt, with additional increases of about NOK 0.05 per additional gram over that. By this estimate, cost of production per fish would be NOK 26.5 for a 410-g smolt and NOK 36.0 for a 600-g smolt. It is worthwhile to note that the last estimate conflicts somewhat with the above indications in terms the degree of linearity in cost accumulation. This estimate is a lot more conservative in terms of reduction in cost per kg of larger fish (see table 5.17). As the table shows, it may also be that the estimated cost of production is a bit low in this study, at least when compared to the industry source.

All studies imply a decreasing cost per kg as the smolts are grown to larger sizes on land, but the assumptions about how significant the reduction in cost per kg might be, differ. Thus, it is not clear how the cost of production can be expected to develop with increasing sizes of smolt. It was emphasised in chapter II that considerable variations seem to exist in terms of smolt producers' facilities and technology, as companies in the industry have become increasingly heterogeneous over time (Sandvold & Tveterås, 2014). Cost of production might vary between both new and existing firms. With the data collected for this study, it is therefore impossible to indicate or believe anything about the representativeness of the assumptions and results.

Either way, the big question of interest to the salmon industry is neither the smolt price, operating margin or cost of production in post smolt operations. Instead, the motivation for investing in post smolt extends to its role and impact on the overall cost of production and associated production risks. During the land based phase, the risks may presumably be shifted to some extent from factors outside of the farmers control – to more internal, manageable and controllable production risks. Moreover, increased smolt size is likely to reduce the grow-out period in sea substantially. The potential increase in control of central growth parameters such as temperature in land based facilities may also lead to a shortening of the overall production time. In effect, many of the industry's current challenges might be eased by a transition to post smolt. However, according to some, the potential for increases in production turnover, capacity utilisation and overall increases in production would be the ultimate prize (Holm *et al*. 2015).

In the following chapter, the analysis of land based post smolt production is extended to looking at the sea based production phase, where the above mentioned and other points will be addressed – with emphasis on cost of production and production planning with use of post smolts.

VI THE GROW-OUT PHASE

In this chapter, we will analyse cost of production for the grow-out phase in sea, based on post smolts. The chapter is focused on cost of production and will explore whether and how the benefits of larger smolts and shorter production cycles may translate into economic advantages in cost of production. The analysis is less extensive than before, taking official statistics on the industry's current cost of production as its point of departure. For this reason, it should be noted that the analysis serves as a preliminary study and that it has some weaknesses. The cost categories given by official statistics are aggregated and involve several sub-components for which we do not have complete information about how they are incurred. For this reason, the assumptions made about potential effects on cost of production by a transition to post smolt are somewhat hypothetical. Nevertheless, the approach is effective in illustrating some important points. In essence, it serves as a preliminary indication as to where and how potential benefits and savings may be materialised – and the costs they need to weigh up for.

Cost of production will be analysed based on 410-g and 600-g post smolts, respectively. In addition to the preliminary study of cost of production, a simple grow-out simulation is carried out to examine the potential effects on production turnover, quantity and license utilisation following a transition from 100-g to 410-g smolts.

As emphasised before, the production cycle can be considerably shorter when using larger smolts. This gives rise to the previously discussed benefits of lower production risk, shorter time between fallowing of production sites and less exposure of the fish to sea lice and lice treatments. Sea lice and diseases will have shorter time to accumulate before a site is emptied, and infected fish may be harvested instead of receiving treatments, as the fish sooner will have reached desirable harvest weights. Some indications also exist that the mortality rate may be lower in post smolt grow-out than among traditional 100-g smolts. For instance, Mathisen (2016) presented experience with smolt and post smolt mortality in sea for various sizes of smolt in the county of Finnmark, Norway in September 2014. The results indicated lower rates of mortality and less variation in mortality rates among the larger smolts.

In general, however, enough knowledge has not been obtained to suggest a specific difference in mortality rates between the two smolt sizes. The mortality assumption in this chapter will be 0.75% per month in the grow-out simulations; 10% over 13 months by use of 410-g post smolt and 9.2% over 12 months by use of 600-g smolts. A mortality rate of 0.75%

per month is consistent with the assumption made by Dahl & Idsøe, but is low compared to the current Norwegian mortality rate in sea[58].

In the following, chapter 6.1, will consider cost of production based on 410-g post smolt while we look at 600 g post smolt in chapter 6.2. One of the most disputed potential benefits of large smolt – namely increased license utilisation and production increases – will be the subject of a separate discussion in chapter 6.3, where production planning and the use of post smolts under the MTB regime will be analysed briefly.

6.1 Cost of production – based on 410 g post smolt

The post smolt analysis will now be extended to explore grow-out of 410-gram post smolt in sea-pens, using the same logic as before to analyse cost of production. Beside the size of smolts released, the production process and annual cost of production in grow-out of 410-g smolts is very much similar to the annual cost of production in operations using 100-g smolts. For this reason, the analysis is simplified by use of available data from the Norwegian Directorate of Fisheries. It might be argued that this is as good an estimate as any.

Nevertheless, some corrections must be made to account for the differences – most importantly to smolt price. However, it is also of interest to examine the potential effects that could be realised if the use of post smolts could enable farmers to increase production turnover and thereby increase production quantity accordingly. Moreover, the elimination of several months per production cycle is believed to reduce lice related costs. To examine the possible effects of these benefits on cost of production, some hypothetical corrections to the official statistics are undertaken.

First, the lengths of the respective production cycles are estimated, by use of post smolt and traditional smolt, respectively. There are two reasons for this: First, there is the potential of reducing the exposure time and accumulation period for sea lice. Second, it is of interest to explore the potential effects of increased turnover in production, provided that a new generation can be released upon harvest of another. The greatest result of such a possibility would be the potential increase in sales and revenues. However, it is also worthwhile to consider the potential gains in terms of cost of production – that is, any "economies of scale" that may exist when fixed and/or indirect costs are distributed over a larger quantity of production.

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[58] After a positive development in 2012-13 with mortality of about 13-14%, the situation has worsened since then, reaching 20% in 2016 (Hjeltnes *et al.* 2017). For comparison, the mortality in Faroe Islands is 10% (Hjeltnes *et al.* 2017; kyst.no, 2017^b).

Given assumptions as described under general assumptions in chapter IV, table 6.1 shows the production time from release of 410 g post smolts in month 0 to harvest of 5 kg salmon in month 13[59].

Table 6.1: Production time from release to sea until harvest, 410-g smolts

Month (beginning)	Weight (g) per fish
0	410
1	517
2	680
3	879
4	1 101
5	1 361
6	1 664
7	1 985
8	2 352
9	2 769
10	3 210
11	3 713
12	4 285
13	5 000

In comparison, the production time using 100-g smolts is estimated to take about four months more, with harvest in month 17. As emphasised before, the long production cycle means that the fish will be exposed twice either to the unfavourable periods of the lowest temperatures and the slowest growth or to the unfavourable periods with the highest risk of sea lice infection. The traditional pattern of 100-g smolt release is highly seasonal with two annual peaks in May and September-October, when most fish are transferred to sea. Using the same procedure and assumptions as described above, figure 6.1 shows the expected weight curve for the two typical releases. As illustrated, there is quite a large discrepancy in the time required to reach a harvestable size of 5 kg. For simplification, it is assumed that harvest of 5-kg fish takes place in month 17, which lie between the expectation for the May release and the October release, respectively[60].

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[59] See appendix, table C4 for details. The weight curve is based on the average of four annual releases with dates of release as given by the land based operations above (December, March, June and September). As the appendix shows, the average weight at the beginning of month 13 is 4,889 g. For simplification, the production time has been rounded off to 13 months.

[60] The weight curves for May and October are given in appendix, table C5a.

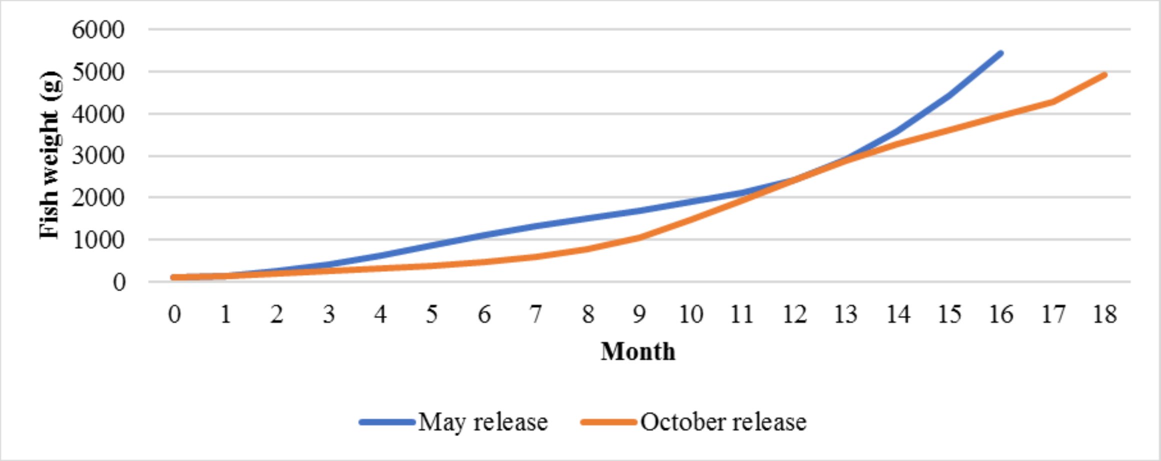

Figure 6.1: Production time from release to harvest, 100-g smolts. Releases in May and October, respectively.

From official statistics from the Norwegian Directorate of Fisheries, we have the current cost of production per kg (see table 2.1, chapter II). Taking this as our starting point, adjustments will be made to account for the difference in production time and potentially quantity by use of 410-g post smolts. In doing so, the most important distinction is between costs that are incurred directly in relation to production and fish growth such as feed, compared to other cost categories such as labour, administration and certain other costs that are less closely tied to the quantity produced. The assumption is that these costs will remain approximately at the same level year-on-year, regardless if a production cycle is completed in 13 or in 17 months. Hence, if a production cycle could be completed in 13 rather than 17 months, the labour cost per kg could be reduced to 13/17 of the current cost per kg. A few conditions are necessary for this to be realised. Importantly, the capacity which is freed up must either be utilised for production (i.e., increasing the production turnover so that in three years, four cycles could be completed instead of three) or eliminated (which is conceivably only an option in the case of labour); here, the former option is our preliminary assumption.

Nevertheless, it must be noted that a major issue in this respect is the limitations imposed by the MTB regime, which dictate an absolute biomass limit both at the level of a location and at the level of the company. We shall disregard this for now and analyse the matter further in section 6.3 below. It can, however, be added that what is assumed here is the maximum conceivable increase in turnover and production resulting from a transition from 100 to 410-g smolts[61].

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[61] The number of months of fallowing between production cycles is assumed to be the same – i.e., two months – after harvest of a generation with either size of smolts. However, over time the number of fallowing months is larger when (only) post smolts are used, as it happens more frequently.

It may, anyway, still not be sufficient to correct cost of production for the difference in production time alone. As the production costs are given per kg of production, it is also appropriate to take account of the fact that for one 5-kg salmon, the produced quantity differs depending on whether 100-gram or 410-gram smolts are released (4.9 kg versus 4.59 kg, respectively). The difference of 310 g would amount to 6.3% of an individual harvest weight of 5 kg, which is not negligible. For this reason, the adjusted components of 410-g cost of production per kg will be multiplied by a factor of 1.063 to account for a lower quantity produced per cycle, in addition to the factor 13/17 to account for a shorter production cycle as described above[62].

To determine which of the cost components that should be adjusted for differences in production time and quantity produced, we must separate between the costs that are fixed or indirect and thus likely to be constant within the relevant production range – and those that relate directly to the production quantity, such as feed and smolts. In addition to the distinction between more and less direct costs of production per kg, two other important items require attention when estimating cost of production based on official statistics – namely smolt cost and interest on license values. Both will be addressed in the following. The cost of production by use of the two production modes is illustrated and compared in table 6.2. Apart from interest and depreciation, the first column is identical to the actual cost statistics for traditional salmon aquaculture as presented in chapter II (table 2.1).

In the official statistics, cost figures per kg contain a certain mortality. As noted above, data on how this may differ over a production cycle and how this may affect the cost of production between the two methods has not been obtained. Smaller smolts and a longer production cycle increases the risk of losses in all phases of the cycle, including for large fish. As mentioned in chapter II, challenges with sea lice have recently led to both reductions in average harvest weight and losses of large fish, both of which lower the final quantity produced and increases the cost of production per kg. Since our estimated 410-g cost of production takes official statistics as its point of departure, we may keep in mind that these could incorporate part of the costs they are supposed to eliminate. In the following, we will examine the possible savings in de-licing costs separately by making assumptions about potential reduction in “other costs”.

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[62] Official statistics define production quantity as: (Quantity sold + frozen stock) + ((live stock 31.12. – weight of smolt released – live stock 1.1.) /1,067), where 1.067 is the conversion rate from live weight to WFE.

Table 6.2: Cost of production production per kg. Traditional farming based on 100 g smolts (2015) and 410-g post smolt (estimate). NOK/kg.

	Traditional farming[a)] (2015), 100-g smolts		Cost based on 410-g post smolt	
Smolt cost	2,72	10 %	7,19	24 %
Feed cost	13,18	46 %	13,18	44 %
Insurance	0,13	0 %	0,13	0 %
Labour	2,07	7 %	1,68	6 %
Other operating costs	6,31	22 %	4,31	14 %
Sum variable costs	**24,41**	86 %	**26,49**	89 %
Depreciation	1,58	6 %	1,28	4 %
Financial costs	0,16	1 %	0,16	1 %
Interest on license value	2,39	8 %	1,94	7 %
Sum fixed costs	**4,13**	14 %	**3,39**	11 %
Total production cost	**28,54**	**100 %**	**29,88**	**100 %**

a) With own estimates for interest on licenses.

Source for traditional farming: The Norwegian Directorate of Fisheries

Like before, we assume the price of a 410-g smolt is NOK 30.00 (table 5.6). If one smolt results in one 5-kg salmon, this corresponds to a smolt cost of NOK 6.54 per kg produced[63]. A question in this respect is whether the cost should be distributed over the full harvest weight or only the quantity actually being produced in sea, i.e., taking account of the size of smolts released. In the official statistics, the quantity produced includes a correction for the size of smolts released, and for this reason it seems appropriate to do the same here (return to footnote 66 above for information). Thus, the quantity produced per 5-kg salmon is 4.59 kg after subtracting the smolt weight. However, it must be noted that this makes it increasingly challenging to weigh up for the higher price of post smolt – the larger the smolts are, the higher the smolt price and the lower the production quantity it is distributed over. It could very well be discussed whether this is the appropriate way to do this. It must also be corrected for mortality during grow-out. If we set this at 10%, the "real cost" per smolt becomes NOK 33 or NOK 7.16 per kg.

Feed cost per kg is determined by the price per kg of feed and the economic FCR (i.e., biological FCR corrected for feed waste and mortality). As noted above, data on the pattern of mortality over the 100-g and 410-g grow-out cycles has not been obtained. Moreover, while the biological FCR is sometimes assumed to be lower and more efficient in smaller fish (ref. chapter IV and V land based), the feed price and mortality may be higher in the period between 100 g

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[63] This number has taken account of the smolt weight, i.e., assuming a production per 5-kg fish of 5,000 g – 410 g = 4,590 g.

and 410 g. The net effect in terms of differences in feed cost per kg in grow-out of 100-g versus 400-g smolt is not necessarily clear-cut, so it may be as appropriate to assume the same feed cost per kg of production in both cases. For this reason, the feed cost of NOK 13,18 per kg is assumed to remain the same in 410-g grow-out. However, if considerable losses of large salmon can be eliminated or reduced by use of larger smolts, then the feed cost per kg should be lower.

In terms of insurance cost, the official statistics do not provide distinctions between insurance on fish stock and insurance on equipment. Thus, the figure may include both. Since investments in physical structures and equipment tend to be relatively moderate in sea based production, insurance of fish stock may constitute a major share of the given insurance cost. For that reason, no correction is made to insurance cost per kg.

For other operating costs, estimates indicate that current costs associated with lice prevention, control and treatment amount to NOK 5/kg or more[64]. With production based on 410-g post smolt, the sea phase is reduced and issues related to lice should be lessened. As an estimate, we assume this will lead to a reduction in other operating costs of NOK 2.00/kg although it must be acknowledged that this is somewhat arbitrary.

When it comes to interest, based on the discussion in Chapter II, a valuation of NOK 80 million per permission is assumed. Also, as noted in chapter II, the average sales quantity (WFE) per permission was 1,338 tonnes in 2015. With no depreciation on license values, interest at 4% amounts to NOK 3.2 million per permission per year and NOK 2.39 per kg.

Financial cost is left unchanged. It is included here as a fixed cost, indicating that it consists of interest on loans, but it may perhaps as well involve interest on working capital.

Wages as well as fixed costs (depreciation and the estimated interest on licence values) are assumed to be incurred on an annual basis regardless of the production model used. For that reason, the cost per kg is corrected for the expected difference in production time per cycle and turnover between the two production modes. We approach this by multiplying the cost per kg with 13/17 to account for the reduced production cycle and 1.063 to account for a lower production quantity per fish due to the larger size of smolts.

In summary, the potential savings in cost of production per kg consist of savings in indirect costs (wages) and capital costs (interest and depreciation) by cost distribution over a larger quantity of output, as well as absolute cost savings in terms of reduction in de-licing cost. Together, the three components amount to a difference of NOK 3.13 per kg compared to the same components in the official statistics, which is equivalent to about 10% of the total 410-g

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[64] For completeness, it should be mentioned that the lice cost in the county of Finnmark is zero (chapter II).

cost of production per kg. The components are presented in table 6.3. As can be seen, the majority of the assumed savings potential relates to a reduction in lice related cost. These, set to NOK 2 on the basis of own judgement, make up two thirds of the total savings. Wages, interest and depreciation together make up one third (whereof 0,39 in wage cost and 0,74 in interest and depreciation). In comparison, the increase in smolt cost is about NOK 4.5 per kg.

Table 6.3 Potential savings in capacity costs per kg of production (as a result of increased production and turnover).

Potential savings (NOK/kg)	Savings (NOK/kg)	% of total savings
Wages	0,39	12 %
Other costs (lice treatment)	2,00	64 %
Depreciation & interest	0,74	24 %
Total estimated saving	**3,13**	100 %
Share of total cost per kg	**10%**	

The information to be drawn from this analysis is that the potential cost savings, here estimated to about NOK 3/kg and primarily related to the cost of sea lice (NOK 2/kg), should preferably make up for the increase in smolt cost. In this case, the increase in smolt cost per kg is about NOK 4.50, and for this reason the total cost of production per kg is expected to increase by about NOK 1.5 compared to the base case.[65]

While the reduction in de-licing cost is based on the elimination of four months in sea, the estimates savings in fixed and indirect costs rely on the possibility of increasing production (turnover). As noted, this assumption will be examined in detail in chapter 6.3.

6.2 Cost of production – based on 600-g post smolt

The analysis of cost of production in grow-out of 410-g smolts can be replicated, using the same procedure and making equivalent assumptions, for the case of 600-g smolts (or 593 to be precise). By use of the 593-g smolts, the production period is reduced to 12 months (compared to 13 in the case of 410-g smolts). On the other hand, out of a harvest weight of 5 kg, the quantity produced in sea is reduced to 4.4 kg. This reduction amounts to 493 g, equivalent to a 10,1% reduction in production per fish compared to the 100-g “base case”[66].

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[65] That is assuming that the realisation of increased production turnover and economies of scale holds true.

[66] Production in sea per 5-kg salmon harvested: 4.9 kg using 100-g smolts or 4.4 using 600-g smolts.

The price of a 593-g smolt is assumed to be NOK 41[67]. In line with chapter 6.1, to find the smolt cost per kg, we divide the smolt cost by the quantity produced per 5-kg fish and correct for mortality. In the 410-g case, we assumed a mortality of 10%. Without evidence of the actual expected difference in mortality between the two scenarios, it may be appropriate to assume that the mortality occurs linearly and that it can be reduced by one month's loss following the reduction of one month of the grow-out period. On that basis, the mortality is set to 9.2%. Under these assumptions, the smolt cost per kg produced is estimated to NOK 10.06.

In common with chapter 6.1, a certain reduction in lice related costs is assumed. Again, this is based on judgment and thus quite arbitrarily determined. Since lice accumulation and infestation is affected by several other factors apart from the length of the specific production cycle for the single company in question, it can of course be questioned whether it is appropriate to assume further reductions in lice cost the more the production cycle is reduced. Nevertheless, it is operated with a further reduction in lice related costs of NOK 0.4 per kg – a slightly lower monthly reduction than was assumed in chapter 6.1 for the first four-months' reduction in production time.

It is again assumed that the indirect costs of labour remain unchanged in the course of a year, irrespective of the length of a production cycle. For this reason, the estimated potential for economies of scale is calculated by multiplying the base case with a factor of 12/17 to account for the increased turnover in production cycles, and furthermore by a factor of 1.101 to correct for the reduction in production per fish of 10.1%. Capital costs, as represented by interest and depreciation, are also corrected using the same procedure. The results are presented in table 6.4, together with the base case and the 410-g case for comparison.

Table 6.4: Cost of production per kg in sea-based grow out. Based on 100-g, 410-g and 593-g smolt, respectively.

	Traditional farming[a)] (2015), 100-g smolts		Cost based on 410-g post smolt		Cost based on 593-g post smolt	
Smolt cost	2,72	10 %	7,19	24 %	10,06	31 %
Feed cost	13,18	46 %	13,18	44 %	13,18	41 %
Insurance	0,13	0 %	0,13	0 %	0,13	0 %
Wages	2,07	7 %	1,68	6 %	1,61	5 %
Other operating costs	6,31	22 %	4,31	14 %	3,91	12 %
Sum variable costs	**24,41**	86 %	**26,49**	89 %	**28,88**	90 %
Depreciation	1,58	6 %	1,28	4 %	1,23	4 %
Financial costs	0,16	1 %	0,16	1 %	0,16	0 %

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[67] Based on the information and sources presented in chapter 5, it is calculated by taking the price for a 100-g smolt, NOK 11, and adding NOK 0.06 per additional gram.

Interest on license value	2,39	8 %	1,94	7 %	1,86	6 %
Sum fixed costs	**4,13**	14 %	**3,39**	11 %	**3,25**	10 %
Total production cost	**28,54**	**100 %**	**29,88**	**100 %**	**32,13**	100 %

As revealed by the higher cost of production per kg, the increase in smolt cost per kg is higher than the estimated savings in de-licing costs and the savings per kg from increased turnover under the given assumptions. It is also worthwhile to note that the smolt cost has increased to 31% of the cost of production, almost approaching the share of feed. In absolute terms, the increase in smolt cost per kg from the base case to 593-g smolt is NOK 7.3. Meanwhile, the potential savings per kg compared to traditional smolts are estimated to NOK 3.75, primarily related to reduction in lice cost (see table 6.5). As a result, the net effect on cost of production per kg is an increase of about NOK 3.60 compared to the base case.

Table 6.5 Potential savings

Potential savings (NOK/kg) - compared to "base case"	Savings (NOK/kg)	% of saving
Wages	0,46	12 %
Other costs (lice treatment)	2,4	64 %
Depreciation & interest	0,88	24 %
Total est. saving	**3,75**	100 %
Share of total cost per kg	12 %	

6.3 Production planning and the use of post smolt under the MTB regime

This section will elaborate further on some key issues in sea-based production and production planning in Norway, comparing releases of 100-g smolts and post smolts of 410-g. The aim of the study is to explore and illustrate possible differences and similarities in how the MTB-regime influences production planning in both production modes. The question is whether and how the introduction of larger smolts may affect the amount of harvest a farm is able to achieve for a given MTB. As emphasised in this chapter, this potential has implications not only for the ability to generate additional revenue, but also for the possibility of distributing costs over a larger production quantity. Such a possibility would increase cost competitiveness and contribute to make up for a higher smolt cost and the likely increase in cost of production by use of post smolt.

Although considerable increases in production and harvest quantity for a given MTB resulting from transition to post smolt is suggested by some (Holm et. al, 2015; Kyst.no, 2017c; Ilaks.no, 2015; Nofima, n.d.; Rådgivende biologer, 2016), it is questioned by others (Mathisen, F., 2016). Because of the MTB design, it may be the case that for companies that already have their biomass continuously adjusted close to the MTB-limit, the possibility to take out any extra production by use of post smolt is negligible or non-existent. To shed light on this question, two separate production planning simulations will be presented. Under similar assumptions, the analysis is carried out using 100-g and 410-g smolts, respectively. The study is based on a production planning design as presented by Dahl & Idsøe (2017). First, a model is established using 410-g post smolts and data as presented previously. Thereafter, a similar analysis is presented using 100-g smolts.

The Norwegian regulation regime was presented briefly in chapter II. As noted, both permissions and locations are required to establish aquaculture operations. A permission is often allowed to be connected to up to four to six locations, so as to enable the farmers to have flexible production throughout the year (Guttelvik, O.B., 2014). The traditional production cycle for one location is to release smolts of 50-100 g with harvest of 4-5 kg salmon (ibid.). A production cycle at a location under these assumptions consists of about 15-24 months of grow-out followed by two months of fallowing.

In the county of Møre og Romsdal, many locations have a production limit of 3,120-4,680 tonnes MTB, as determined by environmental considerations (Guttelvik, O.B., 2014). The complexity of the farmers' production planning problem appears when the farmer not only has to stay within their total biomass cap as given by their number of permissions (the company-level MTB), but must also ensure that their production at no time exceeds the MTB for any single location. A location with an MTB of 3,120 tonnes MTB could for instance contain over a million 3-kg individuals, but only about 600,000 if the weight is 5 kg. To maximise output and achieve a satisfactory MTB-utilisation, farmers depend on having enough flexibility in their production and enough locations to enable the company-level biomass to remain as close as possible to the company-level MTB at all times, without ever exceeding it.

It has been noted that one of the potential benefits of larger smolts is that more robust fish and a shorter cycle may enable farmers to maintain a larger, more stable production by increasing the turnover and number of generations released and harvested throughout the year. The larger fish may also overcome some of the challenges imposed by long growth cycles and the highly seasonal variations in sea temperature and disease related conditions. Although the exact effect of post smolts and a shorter sea phase remains uncertain until actual experience with large-scale grow-out of generations of fish provides evidence of it, figure 6.2 illustrates the expected development in individual fish weights for each possible month of release of post smolts within a year, i.e., January – December. As illustrated, simulations based on previously presented assumptions about actual fish growth provides support of greater seasonal flexibility in production. As the figure shows, the time of release seems to matter a lot less when post smolts are used (for comparison, see figure 6.2 for 100-g smolts). In month 13, all of the releases have reached an "acceptable" harvest weight, ranging from 4,689 g for the March-release to 5,197 for the July-release. Thereafter, the individual fish weights start to spread somewhat again.

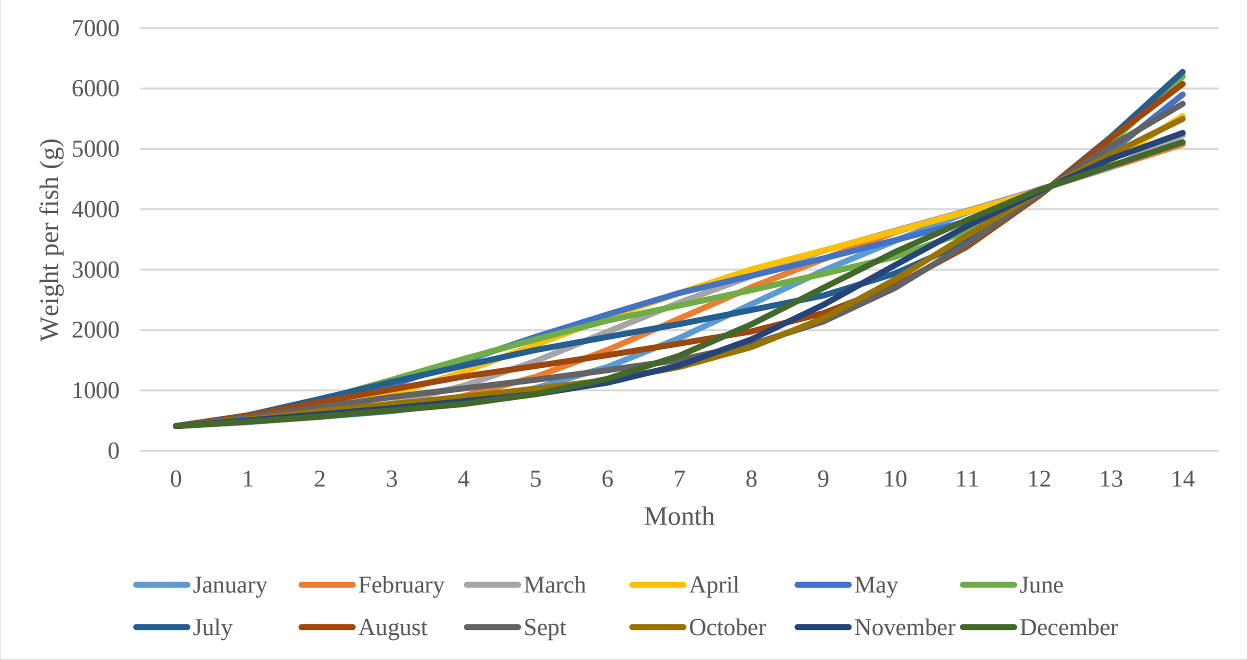

Figure 6.2: Weight curves in grams per fish by month of release to sea (post smolt, 410 g). January – December.
Sources: Assumptions as presented under general assumptions in Chapter IV and in Appendix B. The weight curves are given in appendix, table C6.

The production planning simulations take a company with four licenses of 780 tonnes as its starting point, i.e., a total company-level MTB of 3,120 tonnes. It is assumed that the company has access to six locations. A total of 1,500,000 smolts are released per year, in three batches of 500,000 fish each scheduled for March, July and November. The number of post smolts released has not been subject to optimisation of any kind.

A production plan is developed as follows: the fish are kept for on-growing until the biomass approaches the company-level MTB. At that point, harvest must take place in order to ensure compliance with regulations. For simplification, the production plan is developed on a monthly basis. It starts out with the weight development per fish at each location, with individual fish weights given in kg for the first day of each month, noted as the incoming balance (IB) (see table 6.6).

Table 6.6: Weight curves of individual fish weight per location

Month (IB)	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**
	Weight per fish (kg)					
Mar	0,410					
Apr	0,473					
May	0,594					
Jun	0,785					
Jul	1,078	0,410				
Aug	1,486	0,587				
Sept	1,970	0,857				
Oct	2,455	1,142				
Nov	2,893	1,409	0,410			
Dec	3,310	1,670	0,505			
Jan	3,645	1,884	0,603			
Feb	3,976	2,099	0,705			
Mar	4,327	2,329	0,818	0,410		
Apr	4,689	2,571	0,940	0,473		
May	5,227	2,934	1,130	0,594		
Jun	6,002	3,467	1,417	0,785		
Jul	7,079	4,222	1,843	1,078	0,410	
Aug	8,439	5,197	2,416	1,486	0,587	
Sept		6,276	3,076	1,970	0,857	
Oct		7,301	3,722	2,455	1,142	
Nov		8,191	4,295	2,893	1,409	0,410
Dec		9,015	4,836	3,310	1,670	0,505
Jan			5,265	3,645	1,884	0,603
Feb			5,687	3,976	2,099	0,705
Mar	0,410		6,130	4,327	2,329	0,818
Apr	0,473		6,586	4,689	2,571	0,940
May	0,594			5,227	2,934	1,130
Jun	0,785			6,002	3,467	1,417
Jul	1,078	0,410		7,079	4,222	1,843
Aug	1,486	0,587		8,439	5,197	2,416
Sept	1,970	0,857			6,276	3,076
Oct	2,455	1,142			7,301	3,722
Nov	2,893	1,409	0,410		8,191	4,295
Dec	3,310	1,670	0,505		9,015	4,836
Jan	3,645	1,884	0,603			5,265
Feb	3,976	2,099	0,705			5,687
Mar	4,327	2,329	0,818	0,410		6,130
Apr	4,689	2,571	0,940	0,473		6,586

The monthly mortality rate is set to 0.75% and is assumed to be the same for all locations and months. As discussed in section 6.1, some indications exist that the mortality rate may be lower with post smolt than with regular smolts. However, there is scarce evidence as to how large such a difference may be. For that reason, the following models and estimates use similar mortality rates, with the only difference being a larger number of months with mortality in sea for 100-g smolts. The monthly mortality rate, together with the harvest plan (in number of fish), is the basis for determining the number of fish per site at any time. The number of fish is estimated at the beginning of each month. At the end of the month, all fish either die, are harvested or transferred to the beginning balance of next month. In table 6.7 below, the development in number of fish for the first release(s) at each location is shown. The number of fish at the start of each month is calculated as follows: Number of survived fish from the previous month minus the mortality (in number of fish) and the number of harvested fish in the previous month.[68]

Table 6.7: The development in number of fish per location (given by the survival rate and the harvest quantity)

Release per batch	**Monthly mortality**	**Month (IB)**	**Loc. 1**	**Loc. 2**	**Loc. 3**	**Loc. 4**	**Loc. 5**	**Loc. 6**
		Number of fish (IB = IB Survived fish – previous month's harvest)						
500 000	*0.75%*	Mar	500 000					
		Apr	496 250					
		May	492 528					
		Jun	488 834					
		Jul	485 168	500 000				
		Aug	481 529	496 250				
		Sept	477 918	492 528				
		Oct	474 333	488 834				
		Nov	470 776	485 168	500 000			
		Dec	467 245	481 529	496 250			
		Jan	450 871	477 918	492 528			
		Feb	378 689	474 333	488 834			
		Mar	264 599	470 776	485 168	500 000		
		Apr	178 614	467 245	481 529	496 250		
		May	78 615	463 741	477 918	492 528		
		Jun	0	412 763	474 333	488 834		
		Jul	0	190 787	470 776	485 168	500 000	
		Aug	0	52 916	467 245	481 529	496 250	
		Sept	0	0	378 231	477 918	492 528	
		Oct		0	252 094	474 333	488 834	
		Nov		0	108 053	470 776	485 168	500 000
		Dec		0	44 443	467 245	481 529	496 250
		Jan		0	0	450 871	477 918	492 528
		Feb			0	378 689	474 333	488 834
		Mar	500 000		0	264 599	470 776	485 168

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[68] Regarding harvest quantity, only fish that would otherwise survive to the next month are harvested in this model.

Apr	496 250		0	178 614	467 245	481 529
May	492 528		0	78 615	463 741	477 918
Jun	488 834			0	412 763	474 333
Jul	485 168	500 000		0	190 787	470 776
Aug	481 529	496 250		0	52 916	467 245
Sept	477 918	492 528		0	0	378 231

From the start, the biomass budget is developed for the first two first releases per location without any harvest. This allows us to calculate the development in company biomass if no harvest is undertaken. As the table shows, a separate column keeps track of the incoming biomass for each month. Although that is helpful, it is not sufficient under the MTB regime. Even if we ensured that the biomass on the first day of each month was exactly at (or just slightly below) the MTB of 3,120 tonnes, this would constitute a breach of the MTB rule at the end of the month before harvest: equal to the entire month's net growth (i.e., after mortality but disregarding harvest). For this reason, a company that harvests fish each month (or periodically according to some other defined period, such as per day, week, etc.) would ensure that at the beginning of the period, the biomass is equal to the MTB minus the coming period's net growth. That way, on the day of harvest, forecasted biomass is exactly at the MTB limit – and the company ensures regulatory compliance as well as MTB utilisation[69]. According to sources within the industry, large companies can have production large and continuous enough to maintain daily harvests of the net growth (industry source).

Following the reasoning above, table 6.8 incorporates a separate column for a "net growth forecast" for each month. This again offers the opportunity to determine a "target IB biomass", which is equal to the MTB-limit less the month's forecasted growth. To maintain full control over the biomass situation compared to the target biomass, the fourth column is defined as "target biomass – IB biomass". When the budget shows that the company biomass, calculated on a monthly basis as the sum of IB weight per fish times the IB number of fish across each of the six locations, exceeds the target level, the IB biomass balance becomes negative and harvest must be scheduled for the month prior to exceeding the MTB. The harvest quantity is adjusted until the biomass balance reaches positive territory.

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[69] In theory, this may seem simple but in practice it is not likely so. For one thing, the net growth varies substantially within a year – and can probably vary substantially between years and for all sorts of unpredictable reasons as well. Moreover, the farmer has several other restraints to take account of: to name a few, harvest may for various reasons be restricted to certain periods and to certain minimum and maximum quantities. In addition, harvest and release may be affected by other rules or considerations such as coordinated fallowing which puts restrictions on the flexibility of individual production plans.

It follows from this that we assume that the MTB at the *location level* is not a constraining factor and therefore not becomes binding (i.e., that the maximum biomass allowed per location is “generous” enough to never be exceeded for any of the single locations under this production plan). This way, the focus is on overall production and company-level MTB.

In our example, the company-level biomass exceeds the target for the first time in January, less than one year after the first release (table 6.8). To avoid exceeding the MTB per January 1st, 12,870 fish are harvested in December (month end). Following this harvest, the budget shows that to avoid exceeding the target MTB at February 1st, the harvest in January must be about 68,800 fish, and so on. Harvest is, of course, always first taking place at the location with the oldest and largest salmon.

Table 6.8: The development in company-level biomass and harvest per location.

Month (IB)	**IB biomass**	**Net growth forecast (NGF)**	**Target IB biomass = MTB - NGF**	**IB biomass balance**	**Loc 1**	**Loc 2**	**Loc 3**	**Loc 4**	**Loc 5**	**Loc 6**
					Harvest (number)					
Mar	205 000	29 567	3 090 433	2 885 433	0	0	0	0	0	0
Apr	234 567	58 116	3 061 884	2 827 317	0	0	0	0	0	0
May	292 683	91 140	3 028 860	2 736 176	0	0	0	0	0	0
Jun	383 824	139 091	2 980 909	2 597 085	0	0	0	0	0	0
Jul	727 915	279 015	2 840 985	2 113 070	0	0	0	0	0	0
Aug	1 006 930	356 791	2 763 209	1 756 279	0	0	0	0	0	0
Sept	1 363 721	359 011	2 760 989	1 397 267	0	0	0	0	0	0
Oct	1 722 733	322 503	2 797 497	1 074 765	0	0	0	0	0	0
Nov	2 250 235	351 099	2 768 901	518 666	0	0	0	0	0	0
Dec	2 601 334	286 400	2 833 600	232 266	12 870	0	0	0	0	0
Jan	2 840 826	279 117	2 840 883	57	68 800	0	0	0	0	0
Feb	2 846 369	273 507	2 846 493	124	111 250	0	0	0	0	0
Mar	2 843 547	276 335	2 843 665	118	84 000	0	0	0	0	0
Apr	2 726 015	393 935	2 726 065	50	98 660	0	0	0	0	0
May	2 604 225	515 768	2 604 232	8	78 025	47 500	0	0	0	0
Jun	2 487 012	632 948	2 487 052	40	0	218 880	0	0	0	0
Jul	2 400 897	719 005	2 400 995	97	0	136 440	0	0	0	0
Aug	2 410 885	709 063	2 410 937	52	0	52 519	85 510	0	0	0

Sept	2 527 281	592 714	2 527 286	5	0	0	123 300	0	0	0
Oct	2 661 057	458 892	2 661 108	51	0	0	142 150	0	0	0
Nov	2 714 364	405 547	2 714 453	89	0	0	62 800	0	0	0
Dec	2 816 240	303 728	2 816 272	32	0	0	44 109	12 870	0	0
Jan	2 840 828	279 117	2 840 883	54	0	0	0	68 800	0	0
Feb	2 846 372	273 507	2 846 493	122	0	0	0	111 250	0	0
Mar	2 843 550	276 335	2 843 665	114	0	0	0	84 000	0	0
Apr	2 726 018	393 935	2 726 065	47	0	0	0	98 660	0	0
May	2 604 225	515 768	2 604 232	8	0	0	0	78 025	47 500	0
Jun	2 487 012	632 948	2 487 052	40	0	0	0	0	218 880	0
Jul	2 400 897	719 005	2 400 995	97	0	0	0	0	136 440	0
Aug	2 410 885	709 063	2 410 937	52	0	0	0	0	52 519	85 510
Sept	2 527 281	592 714	2 527 286	5	0	0	0	0	0	123 300

As can be seen from the tables above (see also appendix, table C7), steady state harvest is maintained from January after the first harvest, when the company continues to follow the same pattern of releases and harvests. Given this production plan, each location is scheduled to lie fallow for at least nine months, with nine months of fallowing for the location with the March-release and 10 months of fallowing of the locations with the two other releases.

In terms of production, the budget gives the expected harvest quantity under the assumption that harvest occurs at the end of the month and only fish which survive until the end of the month may be harvested. Harvest quantity in kg is calculated using the outgoing balance (OB) weight per fish (i.e., IB next month) since, by the specifications of the model, harvest is done at the end of the month. For the simulation above, the annual steady state harvest is estimated to 6,175.55 tonnes at UB weight, corresponding to 1,543.89 tonnes per permission. The average harvest weight is 4.5 kg (6,175.55 tonnes divided by 1,366,813 individuals of harvested salmon). For comparison, the average production per license was 1,338 tonnes in 2015 (WFE, only salmon), i.e., 1,428 in live weight.

100-g smolts

We now turn to the same production planning problem in the case of 100-g smolts. Figure 6.3 illustrates the expected development in individual fish weights for 100-g smolts from the point of release to sea, for each possible month of release within a year (January – December). After 12 months, when all of the fish have been exposed to each annual season regardless of the month of release, the weight curves merge. However, whereas the post smolts already were approaching harvestable weights at this point, the 100-g smolts have only reached sizes ranging from 2.393 kg – 2.463 kg. After this point, the weight development spreads again, with growth rates dependent on the temperatures expected in the following months of grow-out. As the figure reveals, the month of release matters a lot more in this case than for 410-g smolts. In months 17-18, all releases have reached an "acceptable" harvest weight, but the weight range is wide: between 4.059 kg (for the December-release) and 6.353 (for the May-release) in month 17 and between 4.553 kg (for the November-release) and 7.166 (for the May-release) in month 18.

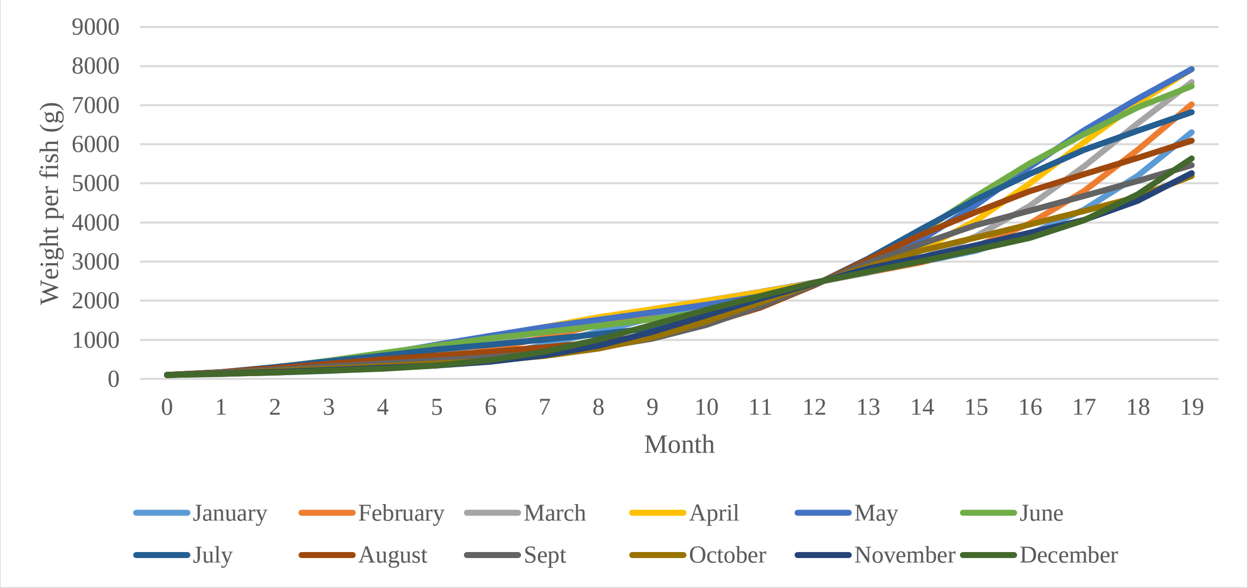

Figure 6.3: Weight curves in grams per fish by month of release to sea (100-g smolt). January – December. (See appendix, table C5b for details.)

As before, we consider a company with six locations and in possession of four 780-tonne licenses, i.e., a total company-level MTB of 3,120 tonnes. The smolt quantity is also the same as before: 1,500,000 smolts per annum in three batches of 500,000 smolts each with releases again scheduled for March, July and November. The fish are kept for on-growing until the biomass approaches the targeted company-level biomass and harvest must be undertaken in order to comply with the MTB.

Given the assumptions stated, the annual steady state harvest is estimated at 5,958 tonnes at Outgoing Balance (OB) weight compared to 6,176 tonnes using 410-g smolts as summarised in table 6.9. This corresponds to 1,489 tonnes per permission (compared to 1,544 tonnes per permission using 410-g smolts). The average harvest weight is 4.5 kg (5,958 tonnes divided by 1,328,760 individuals of harvested salmon). After the last round of harvests per location, each site is laid fallow for at least five months, varying between five months after the November-release and six months after the two others (appendix, table C8).

Table 6.9: Simulation results: Estimated harvest per firm and per license by use of 100-g and 410-g smolts, respectively.

	Number of smolts released	Number of fish harvested	Total harvest (4 licenses)	Harvest per license	Average harvest weight
100-g smolt	1,500,000	1,328760	5,958 tonnes	1,489 (1,396 WFE)	4.5
410-g smolt	1,500,000	1,366,813	6,176 tonnes	1,544 (1,447 WFE)	4.5
Norway 2015	-	-	5,352 tonnes	(1,338 WFE)	-

Discussion and implications of the simulation results

The difference in production quantity for the stylised company between 100-g and 410-g smolts in this hypothetical example is very small – only 218 tonnes per annum. This difference is insignificant and some of it may well even stem from the calculation itself[70]. Hence, for companies which already have adjusted their production close to the limits set by the MTB regulations, support is not found for expecting any meaningful increases in production quantity following a transition to post smolt. More than that, the production quantity given above might overstate the production quantity by use of post smolt, as it has not been corrected for the difference in inputs – i.e., the fact that strictly speaking, the production in sea is 310 g lower for each harvested salmon when 410-g post smolt is used. The finding is supported by simulation trials and analyses carried out by Dahl & Idsøe (not published) and consistent with the view of representatives within the industry (Mathisen, 2016).

What the transition to post smolt leads to in this case is longer periods of fallowing per site. When looking at a location in isolation, we see that a site could have been restocked half a year before it actually is in this case. From this follows the intuitive conclusion that post smolts should lead to faster turnover and increased overall production. However, under the MTB regime the shorter cycle does not translate into increased production when compared to the same company using of 100-g smolts and an equal approach to MTB-utilisation in both

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[70] Harvest in the model is always slightly below the forecasted net growth each month, and the numbers may well be rounded off differently between the models. Moreover, variation in growth "yield" from different sizes of smolts at different times of the year is also of relevance and may randomly or systematically affect the two alternatives differently. As noted, the selection of months and number of fish released has not been subject to optimisation but are selected rather arbitrarily.

cases. Importantly, however, the analysis disregarded restrictions at the level of locations. With the same number of locations and the same approach to production planning and harvest in response to MTB-constraints in both cases, it was not seen how a transition to post smolt automatically leads to increased harvest.

The assumption that the MTB at the location level is not a constraint may not always hold true, particularly for smaller companies with more limited access to locations, fewer permissions and geographical concentration. If, in contrast to our simulation, access to locations or limitations at the level of location-MTB is inhibiting a company from utilising company-level MTB – then it may be that post smolt is a way to address such constraints and thus increase overall production. In general, it seems that the potential for such a production increase is dependent on the specific company's situation in the first place: In the event that companies have suboptimal MTB-utilisation, then post smolt may offer increased flexibility so as to fulfil unrealised potential.

Nevertheless, this is very much an area for further research. In the examples given, only one example of a company in possession of a certain number of locations and permissions was examined. For further studies, the relationship between the number of permissions and locations could be varied. A relevant extension is also to examine various firm sizes and to look at the effect on production from harvesting more and less frequently – although this is more of a general question about production potential than a question related to different sizes of smolts. It is clear that daily harvest gives room for an average biomass much closer to the MTB, implying that the daily net growth would likely be both bigger and harvested more often[71]. According to industry sources, the largest companies can harvest the net growth every day, whereas this is not likely the case for the smallest firms. In terms of differences between small and large firms in Norway, this is relevant.

It is also relevant to explore how the difference in growth relative to fish size affect the possible harvest quantity with use of large and small smolts. In relation to fish size, growth (production) as a percent of the biomass is decreasing with increasing fish size[72]. In turn, this could favour a lower average fish weight to maximise the net growth that can be harvested per period. In the examples given, it has been assumed that three batches of smolts of equal sizes are released every year. The model could easily be extended by considering more batches than

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[71] This simulation has aimed to shed light on the similarities and difference between smolt sizes, and hence more emphasis is put on equal conditions than the effect of various condition of the total harvest.

[72] This statement is a bit problematic in light of current production challenges, where disease and health issues mean that growth relative to fish weight is not only dependent on fish size, but also fish health, sea lice and lice treatments and possibly therefore affected by the length of the production cycle itself.

three. Moreover, production optimisation may imply that batches should not be of equal size and number. Finally, and possibly most importantly, simulations with variation of regulations should be considered. In the examples above, there are MTB-regulations at the location and the company level, but the latter is seen to "drive" the harvesting.

This contrasts to the situation and the regulatory framework on the Faroe Islands, where the introduction of post smolts appears to have led to a considerable increase in production (Østergård, 2016). From 2000-2005, Faroese salmon aquaculture was ravaged by Infectious Salmon Anemia (ISA/ILA), leaving the industry in immense difficulties. The crisis led the industry to implement what is probably the most stringent legislation among salmon aquaculture producing countries (Kyst.no, 2017[b]). Since then, the Faroese industry has transformed to become what may well be the most biologically and environmentally sustainable salmon production regime (Østergård, 2016; Kyst.no, 2017[b]). As noted, the Faroese industry's rate of mortality is about half that of Norway's (Hjeltnes *et al.* 2017).

In terms of production permissions, Faroese legislation imposes restrictions on fish density measured as kg/m^3, but no MTB. Under this regime, Hiddenfjord is one of the Faroese salmon aquaculture firms that has experienced great success with transition to the use of post smolt (Østergård, 2016). Although the primary benefit of post smolt is emphasised as risk reduction in relation to disease, sea lice and accidents in sea, the company reports a major bonus in terms of increased production and improved utilisation of production licenses. As an example, they look at an 84-months' period, i.e., seven years. By use of small smolts, as was common earlier, a production period in sea would consist of 19 months of growth and two months of fallowing – occupying a location for a total of 21 months. In seven years, the company would be able to do four productions. By transition to post smolt, a production period would be reduced to 12 months of growth followed by 2 months of fallowing – occupying the location for a total of 14 months. In seven years, the company would be able to do a total of six productions at the location – an increase of 2 productions in seven years, corresponding to a 50% increase from the previous four, following the introduction of larger smolts.

In this case, it is clear that the transition to post smolt has led to an increase in production. The constraining factor when it comes to biomass under this regime is determined by the maximum density, which is reached just before the point of harvest[73], while importantly, a site is limited to only one generation of fish. Hence, when the required (and desirable) period

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[73] Hence, the number of fish released is adjusted in order to have a generation of at a desirable harvest weight when the biomass approaches maximum density (with due allowance for mortality).

of fallowing is completed, there is nothing inhibiting the firm from releasing a new generation[74]. Under company-level MTB in contrast, a company is inhibited from releasing additional fish because of its existing biomass in other locations[75].

Still, it must be noted that differences between Norwegian and Faroese operating conditions are not limited to the difference between Norway's MTB and Faroese kg/m^3. Importantly, there are several other regulations on the Faroe Islands – and, crucially, the industry structure is very different; probably with some fundamental impacts on how the Faroese Aquaculture Act can be maintained. For the purpose of this review, one practice seems particularly relevant when assessing the implications of the Norwegian MTB so it is reasonable to mention this.

A unique and vital part of the aquaculture legislation of the Faroe Islands is the "all-in, all-out strategy" (kyst.no, 2017^b). Each location or production site is limited to only one generation of salmon and between each Faroese generation, all equipment must be dismantled, thoroughly cleaned and approved by the Food and Veterinary Agency (ibid.). Thereafter, the site must lie fallow for a minimum of two months before a new generation can be released to the fjord. But more than that, the Faroese producers coordinate fallowing and set a limited time window for release of new generations so as to have all locations in a fjord fallow at the same time (FFFA, n.d). Before the new legislation, continuous production in a fjord was the norm (kyst.no, 2017^b). That is, as harvestable fish were taken out at one location, smolts were released at another. In terms of biosecurity and room for disease and parasite accumulation and transmittal, the difference may well be profound.

Because of different industry structures, the feasibility and practical possibility of maintaining such practices are profoundly different in Norway than the Faroes – regardless of legislation. Nevertheless, it may be worthwhile to consider how the MTB-regime may actually contribute to counteract attempts to coordinate fallowing and improve upon biosecurity in Norway. In particular, smaller, geographically concentrated and less flexible producers may suffer penalties in terms of license utilisation under efforts to coordinate fallowing in general and/or within production zones (Salmon Group, n.d; Ilaks.no, 2016^b). Again, a thorough investigation into this issue extends way beyond the scope if this study, but there are clearly

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[74] There are, however, other conditions – some of which will be returned to below.

[75] Alternatively, it could probably reduce its number of fish released at all locations – in exchange for an increased turnover. While this alternative design would allow the producer to an increased turnover while remaining below MTB, brief and not extensive simulations seem to suggest that neither this would imply any meaningful increase to total harvest provided that the producer adapts its biomass to remain close to the MTB at either production design.

incentives for companies to maintain as continuous a production as possible given the locations and MTB in possession in Norway (Guttormsen *et al.* 2012). Whether or not this could conflict with concerns over and efforts towards enhancing biosecurity should be of interest for future research. It is also interesting how under various coordination efforts, differences in company size and geographical production distribution may lead to varying degrees of "penalties" for companies in terms of output reductions – depending on each company's flexibility in MTB utilisation and production adaptation. In the context of new regulations to be introduced with increased regional interdependency among its possibly consequences, the question seems highly relevant (The Norwegian Government, 2017; The Norwegian Ministry of Trade, Industry and Fisheries, 2016; IMR, 2015; NRK, 2017).

To be appropriate, a brief comment should be given about the Faroese industry structure. First of all, the country is a very small producer compared to Norway. After the crisis in 2000-2005, the industry underwent a significant transformation and consolidation, where the number of companies was substantially reduced and is now down to just three, from about 20 at the time of the crisis (kyst.no, 2017[a], FFFA, n.d). Clearly, this has implications for the ability and incentives to coordinate and cooperate. Locations have also been defined and separated more carefully (FFFA, u.d.). If locations are to be operated independently, a distance of minimum 5 km is required; if the distance is less, they must coordinate (ibid.). The country is otherwise small and located in relative isolation with strong currents and efficient natural ecosystem services. However, favorable natural conditions did not inhibit the industry from collapsing prior to the introduction of its new regulation regime in the mid '00s.

6.4 Summary

This chapter has provided indications that under the assumptions in this study, sea based cost of production looks likely to increase somewhat following the introduction of larger smolts. Meanwhile, the possibility of countering this cost increase by increased revenues, production quantity and MTB utilisation seems to be limited to those firms with a "suboptimal" utilisaton of permissions in the first place. The extent to which Norwegian companies in general are able to utilise their MTB optimally is not clear[76]. However, as chapter II illustrated, the ability to produce more per permission has increased continuously over time, potentially suggesting that further "underutilised" potential may still exist. Indeed, Dahl & Idsøe (2016) note that the Norwegian industry has nearly doubled output over time in spite of only marginal increases to the industry-wide total MTB. Looking at the relationship between production output and total

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[76] From official statistics, only the average output per license can be read.

MTB issued for the industry as a whole, this increased from 0.9 in 2005 upon the introduction of the current regulations, to 1.7 in 2015 (Dahl & Idsøe, unpublished).

Although the average quantity sold per permission in Norway has increased over time – also before the introduction of the current MTB in 2005, it is interesting to note that the increased has occurred much in parallel with the increase in firm size and the average number of licenses per company (see chapter II). However, even if production quantities per license have increased while companies have become larger over time, explanations for this could also include technological progress, learning and other effects.

Dahl & Idsøe also note that there are considerable variations in MTB utilisation at the company level. In 2014, data on 95 Norwegian salmon aquaculture companies showed that the average company extracted 1.8 tonnes per tonne MTB (ibid.). At the same time, 20 companies exceeded 2 tonnes per tonne MTB – some approaching 2.5 tonnes of ouput per tonne MTB (ibid.)[77]. Therefore, it seems clear that differences exist in firms' ability to utilise licenses. However, it is not known how large a share of the total Norwegian licensed MTB that belongs to firms with relatively low and high MTB utilisation, respectively. A review of the MTB regime in 2012 stated while "today's production capacity is different from today's production", the actual capacity "is not quite known" (Guttormsen *et al.* 2012). The same study gave a careful estimate, stating that within the existing licensed MTB in 2012, production could probably be increased a further 10% from the current production, which was then estimated to be around 1.2 million tonnes in 2012. While the study by Dahl & Idsøe noted that there are considerable differences in MTB utilisation between companies, Guttormsen *et al.* (2012) noted that it also differs substantially among regions[78].

How different companies approach the MTB utilisation problem with and without post smolt seems to be an interesting topic for further research. The way in which these strategies in turn may influence and be influenced by needs for cooperation and efforts towards biosecurity should also be of interest. One such question is whether company-MTB on the one hand – and initiatives in the form coordination within zonal regions on the other hand – impose conflicting restrictions and incentives upon some firms. In the worst case, this might involve unintended penalties for biosecurity enhancement and rewards for maintaining a most possibly continuous production. Given the nature, accumulation and dissemination of transmittable diseases and parasites such as sea lice, the questions seem important.

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[77] It was also observed that some companies had considerable variations from year to year in the quantity they were able to extract – without simultaneous changes to their available MTB.

[78] Which may be natural as a consequence of differences in sea temperature and correspondingly in net growth.

Notwithstanding the likelihood of increased smolt cost, numerous companies are incorporating post smolts as a main component of their strategy. This could indicate several different things[79]. Possibly, many companies could for various reasons be in a position where there is room to improve their MTB utilisation from the current situation. It could also be that the actual cost of post smolt production is lower than our estimate. Alternatively, it could be that the costs associated with sea lice and biological issues in our calculations are underestimated – and that the savings associated with post smolt, shorter production cycles and less mortality should be higher than outlined in our calculations. Similarly, the industry may expect that sea based challenges will increase from here, so that the benefits will weigh up for the cost in the future. Given the recent development in sea related challenges, companies may see a post smolt strategy as a way to lower production risk and increase production control – and that risk reduction may itself defend a cost premium. The latter points are far from irrelevant – the Norwegian veterinary institute's fish health report for 2016 reveal that increasing resistance among sea lice to medical and chemical treatments has led to a major shift to mechanical lice treatments (Hjeltnes *et al*. 2017). At the same time, in their survey, 93% of fish health personnel reported increases in fish mortality and damages following this type of treatment (which compares to 65% related to medical treatment options). Given the resistance issue and related increase in mechanical treatments, the report notes that mortality associated with lice treatments is poised to remain as large a challenge also in 2017 (ibid).

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[79] Of course, the estimated smolt cost and other assumptions underlying the analysis may be one potential reasons as well.

VII LAND BASED SALMON - MARKETING OPPORTUNITIES

As outlined in chapter II, today's salmon production is primarily concentrated in a handful of countries where the natural conditions are suitable for farming of this species. These countries are Norway, Chile, Scotland, Canada and the Faroe Islands. Typically, the domestic consumption in these countries is relatively limited, with much of the production being traded internationally (with the exception of Scotland's production where a substantial share is marketed in the domestic UK market). Export destinations for salmon are found across the globe. Notable market destinations for salmon include the EU, the US, Japan and Russia. As a rule of thumb, current salmon supply is transported over a long distance.

While land based facilities are being planned across a diversity of continents and regions – including in major salmon producing countries such as Norway – it is commonly emphasised that investment in land based salmon aquaculture has a central feature in allowing salmon production to be located closer to the main markets (other potential advantages include control over the internal aquaculture environment, waste and interactions with the environment; see chapter II). A major advantage to the flexibility in location is the expected cost advantage from saved transportation costs – especially to markets to which today's salmon supply is transported by costly air freight. As illustrated in table 7.1, the cost of air transportation per kg of salmon may amount to as much as NOK 14/kg HOG (DNB, 2017), while other sources indicate NOK 8/kg in air freight from Oslo to the US.

Table 7.1 Total cost to US (or Asian) market for Norwegian sea based and US (or Asian) land based salmon, respectively.

NOK/kg	Sea based (Norway)	Land based (market)
Farm gate cost of production	28.5	38.7
Harvesting	3	3
Total per kg (WFE)	**31.5**	**41.7**
Total per kg (HOG)	**35.5**	**46.9**
Air transport packaging	1	0
Inland transport	1	1
Air transport (US/Asia)	14	0
Total per kg (HOG)	**51.5**	**47.9**

Source: DNB Markets (2017) for costs after farm gate cost of production (as estimated in chapter IV).

Another result of having more flexibility in locating production is the possibility of targeting locations with the best operating conditions for the industry. One point in that respect is the industrial policies in place in various countries. For instance, the EU operates support programmes for fish processing and aquaculture which are not available in a traditional salmon producing country such as Norway (Bjørndal & Ellingsen, 2016). Together with taxes and import duties, such policies aim to strengthen the competitiveness of EU member countries and improve the region's self-sufficiency of fish. Moreover, many countries where land based salmon farming may be established have lower labour costs than Norway.

Accordingly, a direct comparison of cost of production and delivery to market might be more complicated than adjusting for transportation costs. At least in the short term, the availability of a transportation and supply infrastructure and network can have implications for both cost and efficiency of production in new locations. Even production plants located within the national markets require domestic transportation. There is also an unknown magnitude of economies of scale effects – in production, but possibly also in terms of industrial proximity and clustering of support services and related industries, including processing, veterinary services and the sharing of knowledge. Given regulations, scale effects, industrial policies and potential benefits of industrial proximity, one can also envisage competitive advantages other than the sole priority of locating land based facility as close as possible to major markets.

In addition comes differences in the availability, quality and cost of inputs such as water, energy, land and competent labour. Differences in regulations and attitudes towards genetically engineered food is also likely to become a more potent and relevant topic as more regions and nations enter production. Genetically modified (GM) salmon is already underway in the US, where AquaBounty Technologies, a Nasdaq-listed firm, is planning its first commercial scale facility for growing eco-friendly "AquAdvantage salmon," which should not require vaccines or antibiotics (Intrafish, 2017). The company expects to harvest its first salmon in the third quarter of 2019.

Atlantic Sapphire, a Norwegian, newly OTC-listed salmon farming company in the process of constructing a land based plant in Florida, may provide some indications of the expected economies of scale in land based farming. Atlantic Sapphire aims to reach a 2026-production of over 90,000 tonnes and become the most competitive supplier of salmon to the US by using scale to reduce operating costs to levels close to traditional salmon farming – combined with minimal transport cost to the key US market (Undercurrentnews, 2017). According to the company's own fundraising presentation, it aims to bring its costs of supplying salmon to US customers below those for Norway and Chile (ibid).

7.1 Ecological and organic production, product certification and marketing of salmon

As noted in chapter II, global megatrends in the food and consumer markets include increasing awareness towards health and nutrition, sustainability and traceability in food production.

Consumers’ concerns about the environment, health, food safety and food origin may present opportunities as well as challenges to aquaculture production, where pollution, pesticides and the use of medication and antibiotics historically has been a challenge to the industry’s reputation. As noted, new technologies and production models may represent ways of addressing some of these concerns. Land based producers have frequently noted these trends, seeing opportunities for product differentiation by emphasising a sustainable, fully traceable and potentially domestically produced salmon.

Indeed, one of the central marketing claims from potential entrants to land based salmon aquaculture is its environmental advantages and opportunities for producing organically[80]. The principal claim of organic production is to offer a long-term perspective for sustainable aquaculture at three levels: social, ecological and economical (Aquaculture Europe, 2013). Organic aquaculture is regulated through the EU regulations on organic production and labelling of organic products (EU Council Regulation 2092/91). The EU organic logo and labelling rules are an important part of the organic production regulations (European commission, n.d.).

Aquaculture Europe, a magazine published by the European Aquaculture Society, provides production statistics for organic fish production in 2012 for the main European producing countries (Aquaculture Europe, 2013). With more than 80 % of the whole European organic production, salmon was the major certified species in Europe in 2013 (ibid). However, as a share of the total European salmon production, only 1.4% was organic in 2012. The main organic salmon producer was Ireland. It produced 9,600 tonnes – half of the European organic salmon supply, accounting for 70% of the country’s total production. Most of it went to French and German markets. While Norway accounted for more than 80% of the total European production, less than 1% of production was labelled as organic (about 8,000 tonnes) – with all organic production going mainly to the UK and Germany. During the five years prior to 2012, the production of organic salmon had decreased as a function of higher costs in a difficult market with cyclical prices. Furthermore, the use of medicines to control diseases and parasites (especially sea lice), the effects of escapees and the increasing use of land-based vegetables in

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[80] In organic/ecological production, natural resources are to be managed so as to avoid harm to the environment. Ecological aquaculture implies that operations are managed with care and concern for the environmental footprint as well as the health and wellbeing of organisms. It entails farming of various species as well as harvesting, transportation and sales of the products and may include a focus on local and renewable resources. The surrounding environment should be affected as little as possible by the operations, including any transfer of disease, parasites and medicines to the wild. Feeding is managed so as to contribute to a natural feed intake with minimal waste. Feed ingredients (oil and meal) should stem from organic agriculture or from the fish waste generated by sustainable fisheries, with the feed often involving a large share of marine ingredients. Additives are not allowed in organic feed.

salmon feeds had been challenges to organic certification. Hence, only two farms were certified organic in Norway in 2009 (ibid). In the UK, 14 farms produced 6,122 tonnes of organic product in 2010. However, in 2011, only about 2,900 tonnes was produced.

In its 2012 Annual Report, the Federation of European Aquaculture Producers (FEAP), outlined the main challenges in organic production – including feed specifications, husbandry measures, limited stocking densities and higher costs (Aquaculture Europe, 2013). National or local legislation is not always adapted and often prevents producers from starting organic production (ibid). Moreover, the term ‘organic’ is also interpreted in a multitude of ways and the number of certified labels does not help consumers to see more clearly (ibid).

There are currently no special organic certificates available for land based salmon. The existing European standards for organic salmon require a maximum of 10 kg of fish per m^3 to avoid stress or skin damage and to allow the fish to shoal (Debio.no, n.d.). In Norway, none of the planned facilities assume a fish density below 40 kg per m^3, and land based operations would struggle to reach profitability at such low densities.

As of today, organic salmon seems to be a relatively limited market niche in terms of overall quantities, although an updated set of data has not been obtained – either for production or prices. Aquaculture Europe noted in 2013 that “if organic production becomes more than a niche market, it loses its inherent market premium. As other standards and ecolabels are used to demonstrate aquaculture credentials, the option to produce to organic standards should logically be based on small volumes to satisfy relatively small demand” (Aquaculture Europe, 2013).

In terms of ecolabels and other standards for sea farmed salmon, other, less comprehensive certificates than the organic standards are already being more widely applied. The Aquaculture Stewardship Council (ASC) is an independent, international non-profit organisation that manages the world’s leading certification and labelling programme for responsible aquaculture (asc-aqua.org, n.d.). The ASC salmon standard has been in operation since 2012 and aims to address the key negative environmental and social impacts of salmon farming associated with: sourcing of feed ingredients, disease transmission between farms and into wild salmon populations, controlling escapes into the wild, use of therapeutics and anti-biotics, site impacts, the presence of GMO products in feed and labour issues on farms (asc-aqua.org, n.d.).

All farms certified to the ASC Salmon Standard must meet a total of 154 performance criteria and 521 compliance criteria, thereby showing they deliver real environmental and social benefits (The Fish Site, 2017). Recently, in June 2017, ASC certified farmed salmon also became officially endorsed by the Monterey Bay Aquarium's Seafood Watch standards as a 'Good Alternative' and a recommended, sustainable form of seafood (ibid.). Their 'Best Choice', however, is Atlantic salmon farmed worldwide in closed tanks (labeled as "land-based" or "tank-based" salmon), following the arguments that closed tanks often have less effluent, disease, escapes and habitat impacts than other aquaculture systems (Seafood Watch, u.d.). Currently, only 0.1% of farmed Atlantic salmon is produced in closed tanks (ibid.).

At the end of 2015, the number of ASC certified aquaculture farms exceeded 200 globally (Wwf, u.d.). Salmon was the largest product group, with 84 out of the total number of farms – most of which were located in Norway (ibid.). At present, nearly a quarter of all famed salmon produced globally is ASC certified, and members of the Global Salmon Initiative (GSI) are the main sources of ASC-certified farmed salmon. The GSI is a collective of the leading global salmon farming companies that have made it their target to be 100% ASC certified by 2020 (The Fish Site, 2017). Polish aquaculture producer Jurassic Salmon became the first land based salmon farm to achieve ASC certification in 2016. It is also the world's first fully organic Atlantic salmon farm, using thermal ground water from 150 million years ago (Fish Update, 2017).

7.2 Could there be a price premium for land raised salmon?

Expectations and speculations about the possibility of a price premium for land raised salmon tend to be grounded in beliefs about possibilities of organic production practices and certification schemes, as organic products tend to fetch higher prices in the market. Some attributes that the land based aquaculture producers might seek to emphasise include:

- Management of the aquaculture environment to best possibly meet the needs of the fish
- Waste control and possible reuse/recycling of the waste
- Disease and parasite control (particularly with respect to interactions/transfer to the wild)
- Possibly reduced need for chemicals and treatments – at least reduced or more controllable impact of such use on the surrounding ecosystems
- Fish welfare and associated product quality
- A safe and controllable working environment
- Origin/locally sourced food

For land based salmon to realise premium prices in the market, the relevant product attributes would need to be accepted by consumers and associated with land based production in general, as superior to sea based alternatives. Trusted certifications schemes might be one way to build an organic image, while branding by single producers likely requires substantial scale to achieve the same. It is anyway hard to expect the outcomes in advance, and the question of both price premium and sustainability of production might depend on individual firms' strategies and level of success.

As previously referred, a study by Liu *et al* (2016) compares the carbon footprint of salmon produced in traditional open net pen production system in Norway and a model freshwater RAS facility in the US. According to their findings, the carbon footprint of land-based salmon produced in the US and delivered to the US market is less than half of that of salmon produced in traditional open net pens (ONP) in Norway and delivered to the US by air freight[81]. When comparing the carbon footprint from production only, the RAS-produced salmon (assuming the average US electricity mix) has a carbon footprint that is double that of the ONP-produced salmon. Assuming use of energy from water only, the carbon footprint is fairly close for the two alternatives, but still slightly higher for RAS. Consequently, conclusions and promotions about climate friendly production modes will likely need to be considered more carefully than just based on the production technology itself.

The spread in operational and biological success among all land based operations might also affect the image of the producer group as a whole. Just like there is variation in production practices among sea based producers and producer countries, there could also be a wide range in the level of fish welfare, medical use, waste management and product quality among land based salmon farms globally. In that sense, certification schemes might be more of a differentiator between good and bad producers than between good and bad technologies. Still, differences between technologies with respect to the availability and ease of achieving and proving the required performance to be certified could come to exist. As certification schemes of varius sorts become more mainstream and widespread, expectations are also evolving and one might ask whether various certifications themselves will enable price premiums in the long run – or if they increasingly will be expected or even required to get access and contracts in the distribution chain.

Nevertheless, local or domestic production might give land based farmers an edge in their marketing efforts. This could both take the form of consumers' preference for local products and their own country of origin as well as the possible marketing intelligence that

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[81] The results of the carbon footprint analysis confirmed that production of feed is the dominating climate aspect for both production methods, but also showed that energy source and transport methods are important. It was shown that fresh salmon produced in RAS systems close to a US market that use an average US electricity mix (coal 50%, water energy 50 %) have a much lower carbon footprint than fresh salmon produced in Norway in ONP systems shipped to the same market by airfreight, 7.41 versus 15.22 kg CO_2eq/kg salmon HOG, respectively.

results from proximity to consumers; sensitivity to and understanding of their product preferences and habits. In general, product quality, consistency and reliable distribution are important for market access and price. While it is possible to assume that land based facilities could get their fish to the local markets within a somewhat shorter time (at least to some market places), questions such as the required scale of production and marketing make it difficult to assume any distinctions between land and sea based production with respect to distribution.

The discussion so far about the price of land based salmon has centred on the potential benefits of land based production. At the same time, less is said about potential benefits of sea based production. Some counter arguments to expecting higher prices and a better image for land based production could include a lower energy and oxygen consumption in sea, water conservation, low fish density and generous space and the potential exclusiveness of fish that are «raised in the wild». In contrast, land based salmon are in fact raised in factories at much lower densities – which in other cases, such as in chicken farming, has rather less of a positive image. Some possible challenges to product quality in land based salmon farming have already been experienced by existing producers. These include skin damage resulting from high densities, off-taste resulting from the water culture and early maturation. While companies seem to report considerable improvement in managing, understanding and avoiding these issues, much remains to be learnt and understood about the optimal conditions for fish in land based systems.

When it comes to summarising expectations about the price of land based salmon, it seems likely that the range of operating practices, fish welfare, biological and medical success in farms around the world – together with marketing, certification schemes and quality control – all will be part of determining the outcome in the longer term. While certified fish might contribute to price premiums over non-certified fish, the discussion has indicated that it might be optimistic to assume a price premium resulting from the production technology itself.

While this chapter has considered land based salmon compared to traditional sea based salmon, another point about salmon price is the possible effect from the introduction of land based technology on industry dynamics and structure as well as the global price of salmon. This will be left for a brief discussion in the next chapter.

VIII SUMMARY AND DISCUSSION

To summarise the findings and results from the research, this chapter will discuss each of the main analyses separately before closing with a recommendation of areas for further research. First, land based farming of salmon is discussed in chapter 7.1, with emphasis on competitiveness and comparison with conventional production. Second, the analysis of land based production of post smolt is discussed in chapter 7.2. The findings about post smolt grow-out in sea are discussed in chapter 7.3, both in terms of cost of production and issues related to production planning.

8.1 Land based farming of salmon

This study has indicated that with today's knowledge and under the assumptions presented, land based salmon aquaculture technology might offer an interesting and economically viable way of producing salmon. Yet importantly, the cost of production analysis indicated that to be profitable, land based producers might still need to fetch a higher price than sea based farmers need – at least in a Norwegian context[82]. This means that a land based investor in this context takes on considerable market risk – in addition to the biological and technological risk. Should the balance between supply and demand change in the future, that is a risk for producers with a higher cost of production. Nevertheless, the technology is still in its earliest phase and entrants may be expecting that as technology progresses and biology is increasingly well understood, production may be expanded, economies of scale and learning effects realised and cost of production come down.

The comparison with other studies showed that the estimated cost of production in this study is relatively high – although the estimate made by Liu *et al.* (2016) based on a US context is not very far below. Still, as underlined, with respect to the existing literature the context as well as the assumed cost structures are different from study to study. And equally important, we are talking about a new technology so that empirical data on cost of production of this scale are non-existent. For this reason, it is acknowledged that adopting a stochastic methodology such as King *et al.* (2016) could have contributed an added value to the deterministic approach used in this study. Their study addresses the implications of economic risk on technology selection by incorporating stochastic variance in a comparative analysis of salmon grow-out production models. An important argument for doing this is to enable decision makers to develop an awareness of economic risk by visualising differences in variability of expected results. Without accounting for variance in investment appraisals managers might not make the

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[82] The analysis looks at farm gate cost of production before harvest, processing, transport and sales related costs.

most appropriate decisions (King *et al.* 2016). The current analysis accounts for risk and uncertainty by undertaking sensitivity analyses for specific components to reveal specific risks and areas of importance. Although that is useful and contributes important managerial insights, it does not reveal the variability profile for a project as a whole (which is of interest in a decision-making situation). This could be an area for further research.

In terms of comparing land based cost of production with the alternative production modes, the current study has its limitations with respect to the sources of data used. The approach to data collection and analysis is very different between the land based and the sea based production parts. The official statistics used to analyse sea based operations are from two years back in time (2015), and with a correction for interest on license values as shown in chapter VI. Land based data are collected in 2017, based on expectations. Part of the discrepancy could be addressed by accounting for inflation. However, another issue would remain, which is the possible increase in lice related costs since 2015. Given the recent development in lice treatments and treatment resistance problems, it is possible that the 2015 data underestimate the lice related costs of today.

Table 8.1 summarises the estimated farm-gate cost of production per kg (WFE) by use of full land based grow-out, traditional production (2015) and 410-g smolts. The last row remains empty as a reminder of the uncertainty related to current lice related costs in sea based production. If the cost is inflated to 2017-prices, the cost of production per kg for the two latter scenarios becomes NOK 29.74 and NOK 31.13, respectively[83].

Table 8.1. Cost of production per kg (WFE). Land based full cycle production and sea based grow out of 100-g smolts and 410-g smolts, respectively.

	Land based NOK/kg	**Traditional farming (2015), 100-g smolts$^{a)}$**	**410-g post smolt$^{b)}$**
Feed	16,1	13,18	13,18
Roe/smolt	0,3	2,72	7,19
Labour	2,3	2,07	1,68
Other variable costs	12,5	6,44	4,44
Sum variable costs	**31,2**	**24,41**	**26,49**
Interest and depreciation on investments	6,6	3,97	3,22
Other fixed costs		0,16	0,16
Sum fixed costs	7,5	4,13	3,39
Total production cost	**38,7**	**28,54**	**29,88**

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[83] The figure is for 2015 and has been adjusted to 2017 level to account for price increases (CPI 2015 = 100, January 2017 = 104.2).

Increase in cost of sea lice since 2015	-	?	?

[a] With own estimate added for interest on license value.

[b] This cost is based on increases in production quantity and turnover as estimated in chapter 6.1: Assuming an increase in production equivalent to the increase in turnover following a transition to 410-g smolt (corrected for smolt weight) – leading to lower cost per kg from labour, interest and depreciation as well as a reduction of NOK 2/kg in lice related costs. If we instead assume that the cost of production per kg stays the same as in traditional farming (2015) and add the increase in smolt cost per kg (7.19-2.72) while subtracting NOK 2.0 in anticipation of less lice treatments, then the cost of production becomes 31.01/kg. The difference is relatively small because as noted in chapter VI, lice related costs are assumed to constitute the most important potential for cost savings by use of large smolt.

As the table shows, farm-gate cost of production is expected to be higher in land based than in sea based grow-out, while production using large smolt is a bit costlier than 100-g smolt. The engineering costs used to estimate land based full-cycle production and cost of production per 410-g smolt might not be directly comparable with the average production costs reflected in official statistics. Moreover, the pricing or transfer price of smolts represent another problem for the estimated cost of production. For an integrated firm, the smolt price might have been set differently than that in our study. As recalled from chapter V, the smolt price paid by sea based grow-out farms includes a margin – also reflected in the positive NPV which was estimated for investment in post smolt production. Again, it can be emphasised that the interest in salmon producing firms is likely often neither the smolt price, cost of production or NPV from post smolt production in isolation. Instead, the motivation relates to its impact on overall cost of production and production risk for the firm as a whole.

For this reason, a complete analysis of an integrated firm with both smolt and grow-out production is likely to provide the best picture of the attractiveness of investment in post smolt, looking at both overall cost of production and NPV over a certain horizon. Such analysis was not undertaken in this study, but a brief discussion of the separate findings is given below. However, we shall first revert to an overall discussion of the price and market issues briefly mentioned in chapter IV about land based competitiveness and relative attractiveness as an investment opportunity.

It was noted in chapter IV that the price assumptions underlying the investment analysis are formed in the context of constrained supply, good market demand conditions, a favourable currency situation (in Norway) and cost related challenges in many traditional salmon producing countries. Meanwhile, the NPV analysis suggests that there is potential for land based salmon aquaculture to be a profitable investment opportunity also in Norway – but the result is highly dependent on price. Given that market analysis and price forecasting is not done in this study, the theoretical foundation for choosing a certain price and price development over the projected horison is a weakness of the analysis. As noted, the price assumed was based on the average forward contract price for the limited period for which it is available – and taken to remain the same in real terms over the projected period in lack of a better estimate[84]. To consider how and why this might be a weakness, it is worthwhile to look especially at the historical price, as well as to the current price and the potential future price drivers.

Historical price

Historical real prices have, since economies of scale and learning effects were increasingly exhausted after the 1990s, fluctuated but remained high relative to real cost of production in real Norwegian kroner – in spite of increased global supply (figure 2.1). This is thanks to high and steadily increasing demand – and, given that abnormal profits apparently have been sustained for some time for the industry, it is likely also in part a result of high barriers to enter the industry (in the form of both regulations and natural conditions).

Current price

Compared to historical prices, the real salmon price level – particularly in NOK – over the last few years (2015-2017) is very high. For the Norwegian industry, where most of the quantity is exported, the exchange rate situation must be considered in order to evaluate the price faced by buyers in the market. In 2015, Norway experienced record high seafood export values, in particular for salmon (and cod). However, while exports increased by 8 percent in terms of the Norwegian krone, in US dollar terms they declined by 16 percent. The fact that the Norwegian currency has been relatively weak in recent years (following the oil crisis starting in 2014) has helped Norwegian salmon exports to stay competitive in spite of rising cost of production. Hence, should the currency strengthen, this may very well be expected to put pressure on prices in real Norwegian terms – which might be painful if the current cost trend is upheld[85].

Future expectations – price, demand and supply

In the future, prices as well as exchange rates between countries may change. The latter factor is nearly impossible to foresee and to account for. Otherwise, as far as prices are concerned, both supply and demand are central. It is not possible to predict future development in either of

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[84] That was a bit less than three years forward in March 2017, to the end of December 2019.

[85] Although possibly costs such as imported feed may weigh up. However, this need not necessarily work as a currency hedge either, as relative developments in the feed producing currency may not coincide with the development in salmon export destination countries.

the two within the scope of this analysis. Nevertheless, in analysing the feasibility of a technology that has the inherent feature of bypassing current entry barriers to salmon aquaculture, it would be conspicuous not to mention the potential feedback effect on prices in the event that the technology succeeds. It would take quite a few land based salmon farms to contribute a meaningful contribution to the global salmon supply – enough to affect the global salmon price. On the other hand, as long as the outlook for increases in sea based production is limited by disease problems and/or regulations, the expected NPV in a land based project may, even with room for some biological challenges, look promising enough for many to take the risk. In terms of new entrants, many seem determined to start out gradually, building out facilities in smaller modules initially, before planning to expand production as biology, technology and concepts eventually prove their success. One such example is Atlantic Sapphire, which plans to build the first part of their US salmon aquaculture facility as a module with 8,000-tonnes production capacity, before expanding over time to 90,000 tonnes in a development process consisting of three steps (ilaks 2017b).[86]

Moreover, factors that have been disregarded in this study may contribute to lowering the bar: investment grants and subsidies, tax conditions; locational advantages in many forms; advantages in logistics and transport cost; differentiation, marketing and consumers' product perceptions and preferences in terms of local produce, environmental impacts, concerns over diseases and chemicals, etc., as well as potentially the regulatory environments[87]. Looking for instance at the Atlantic Sapphire example above, important factors include transportation cost advantage over exports from Norway (NOK 8-18/kg according to various sources, such as DNB 2017 and industry representatives). In addition, the company focuses on "made in USA" in their marketing (ilaks 2017b). Looking at table 7.1, this transport cost advantage is sufficient to weigh up for the difference in estimated farm-gate cost of production in land based and sea based production in Norway.

With today's price assumptions, knowledge and available technology, there are incentives to invest in land based production for those who believe in their ability to manage fish biology and to acquire the necessary competence to operate a fish farm. Should the first-

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[86] In comparison, the total import of salmon to the US was 133,175 tonnes in 2016, implying that the company is aiming to supply 67.6% of the current import quantity (National Marine Fisheries Service, 2017). In terms of strategy, this is an interesting signal or statement, potentially indicating both considerable scale advantages in various forms (which could range from production, marketing, logistics as well as even risk) while it also reminds a bit of a "preemptive" commitment signal.

[87] Some of these factors, such as logistics, transport cost and taxes may also alter the relative cost of production between the production modes. As Liu *et al.* (2016) showed, location of production closer to major markets may also turn out to reduce the environmental footprint – at least to those markets where the current means of transport is by air freight.

movers succeed, most have ambitions to expand production as soon as sensible to take advantage of economies of scale (see table 4.1). On the cost side, new differentiators may emerge based on locational advantages in many forms, as mentioned above.

Meanwhile, traditional sea based farms are striving to improve upon their operations and take control over biology and related costs and build a foundation for sustainable expansion[88]. Given the salmon price and the typical cost of production today, both modes of production constitute attractive investments. In other words, under current limitations to global supply, prices are sufficiently high to accommodate also producers with relatively high cost of production. Indeed, investments are flowing into research, development and technological solutions related both to traditional and alternative production models – in traditional as well as some untraditional producing countries. Both the sources of future salmon supply and the price consumers will be paying for it looks likely to depend in part on the alternative production models' absolute and relative ability to provide a healthy environment the salmon, where it can be grown sustainably.

It is not easy to guess how the balance between supply and demand might change in the future – or for that matter how soon any potential changes could be seen[89]. In theory, the incentives to invest in land based aquaculture (in Norway) remains until price expectations approach cost of production, which is adjusted for cost of capital. At this point, competitive sea based producers (in Norway) would still have incentives to increase their production – if regulations and biological conditions allow so. For this reason, in the event that land based aquaculture succeeds on a large scale, it seems reasonable that a NPV analysis would need to incorporate a declining price trajectory over the years, in line with expansion of global production. Should sea based production also improve on biological issues and costs, prices might be even more competitive in the future. It follows from this that the NPV-analysis for a 20-year period of an investment like this is highly uncertain.

Should the salmon price come down, this would also affect the value of existing production permissions. That would be critical for any producer who had invested in a production permission at the current value. This is important in terms of investment risk. While production permissions probably have no alternative use, it is not easy to say anything about the potential alternative use of a land based facility – a stranded asset or for instance of use in

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[88] History has previously shown that health related challenges may lead to needed actions and reforms, see for instance chapter 6.3 for one example.

[89] Of course, many considerations are relevant in that respect, including the relative prices of other products, technological development and regulations, general economic developments and probably more.

production of other high value species. Aquaculture production in RAS systems is still in its rather early development, so it is in many ways challenging to assess the riskiness of the investment.

8.2 Post smolt production on land

The analysis of land based smolt production indicated that investments in production of post smolt may be a profitable investment and that economies of scale might exist. Although there are few references for comparison, the available estimates from other published sources showed similarities in their findings of cost of production – but a question remains when it comes to the shape of the cost curve as the smolts are grown larger in land based facilities. Cost of production per kg is decreasing with increasing fish size, but it remains uncertain how and by how much.

Uncertainty in post smolt production is associated with variations in the technology and level of investment as well as the related cost of production – labour demand, level of automation, water sources (fresh or sea water), energy for pumping and heating (if the water is to be heated), other cost of production, etc. In addition to differences in new-built facilities, the solutions which can be found in the industry may vary even more[90]. With the data collected for this study, it is therefore not reasonable to indicate or believe anything about the representativeness of assumptions and results. Possibly, research at the intersection between biology, technology and economy would be the most rewarding. For this reason, the discussion of results and findings is drawn towards other areas such as technology and biology – where many areas for further research can be found, but which are beyond the remit of this study.

Nonetheless, a central point with respect to the analyses of investment in production of post smolt is that the investments are often done by integrated firms, whose interests are centred on the overall company performance, cost of production and associated production risks. During the land based phase, the risks may presumably be shifted to some extent from factors outside of the farmers control – to more internal, manageable and controllable production risks. Control of central growth parameters such as temperature in land based facilities may reduce the overall production time and raise more robust fish for release to sea. Yet perhaps most importantly, it reduces the grow-out period in sea substantially, thereby addressing problems related to sea lice accumulation and exposure to transmittable diseases. For this reason, economic analysis of post smolt is most valuable when analysed together with full grow-out operations.

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[90] Because of building standards and requirements to inhibit escapees, it seems that standards are generally high in newly built facilities.

8.3 Post smolt grow-out in sea

The analysis of post smolt grow-out in sea provided indications that under the assumptions in this study, sea based cost of production looks likely to increase somewhat following the introduction of larger smolts. Chapters 6.1 and 6.2 anticipated how the cost of production in sea based grow-out could be affected upon a transition to use of post smolts. It was examined whether and how the increase in smolt cost (price) could be countered by potential rewards from increased production turnover. It was argued that if new generations of fish can be released and harvested continuously, there might exist possible savings in "capacity costs" (i.e., fixed and perhaps some indirect costs). The reason is that those costs could then be distributed over a greater production and hence reduce the cost of production per kg.

Chapter 6.3 examined further the possibility for such production increases by simulating a production plan using 100-g and 410-g smolts, respectively. The objective was to examine the potential increase in MTB-utilisation following a change to post smolt. A central assumption in the simulation was that the company's production capacity was determined by its number of production licenses – i.e., its company-level MTB. The simulation illustrated the importance of having as much fish as possible in sea at all times in order to maintain a continuous harvest as high as possible. The findings showed that when the company is equally able to keep its biomass at about the company-level MTB at all times in both smolt scenarios, support for expecting meaningful increases in harvest quantity is not found. Thus, the possibility of achieving increased revenues, production quantity and MTB utilisation by transition to post smolt is dependent on a firm's ability to maintain a company-level biomass about equal to the MTB in sea at all times in the first place. Hence, a transition to post smolt does not automatically translate into increased production when company-level MTB is assumed to be the only constraining factor.

This finding might be a bit surprising, considering the expectations reported by several companies and reports (Holm et. al, 2015; Kyst.no, 2017; Ilaks.no, 2015; Nofima, n.d.; Rådgivende biologer, 2016). Two main explanations seem reasonable. First and foremost, the assumptions in the simulation do in all likelyhood not hold true for all firms in the industry: MTB at the level of the company is not the single determinant of production capacity. That is, other constraining factors contribute to determine how much a company can produce given their licenses. Although the other relevant constraining factors and how they impact individual firms are not explained by this study, it seems likely that the number of locations and location-level MTB constitute a central part of the explanation. The geographical production regions to which a company's locations belong add another dimension to the problem when regulations such as coordinated fallowing or regional MTB apply. Modelling these issues is much more complicated, because the number of locations, their respective location-level MTBs (and relevant geographical region if associated regulations apply) and the number of permissions associated with the locations vary individually between companies. For this reason, the effect of post smolt on production quantity and cost of production per kg is also likely to vary somewhat between companies. Those companies currently facing the most constraints to MTB utilisation might see relatively more benefits from a transition than the companies at the top of the range. For the former companies, both production increases and savings in capacity cost per kg of production[91] might potentially be achievable by use of larger smolts.

Another relevant and possible explanation for companies' positive expectations and investments in post smolt despite our simulated and cost related findings is the previously discussed benefits related to fish health and sea based production risks. Comments from industry representatives indicate that even the largest firms anticipate higher harvest from their standing biomass with use of large smolts (200-300 g) as a consequence of larger daily net growth and fewer lice treatments[92].

As noted, the simulation carried out in this study was limited to a complete shift from 100-g smolts to 410-g smolts – all else equal and with an equal approach to "full" MTB utilisation (given a monthly harvest interval). Some companies that expect their MTB utilisation to increase by use of post smolt may also be aiming to exploit the flexibility it offers in different ways – to specifically address their relevant constraints to maintaining a continuous production and a standing biomass close to the MTB. One example of this could be the use of large smolts together with small smolts at a location in order to utilise location-level MTB (kyst.no, 2017d). Large smolts may then be ready for harvest at a time when the company traditionally would not have fish ready for harvest, and thus help to maintain a more continuous production[93]. While that may allow a company to address MTB-concerns, other benefits of post smolt such as more frequent fallowing do not seem to be realised when normal and large smolts are combined in one location – potentially also conflicting with other biosecurity concerns, although this is a bit of speculation. Anyhow, the ways in which MTB at various levels of regulation distort or affect production patterns and firm behaviour seem to represent under-researched areas.

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[91] Such savings would depend both on the magnitude of the production increase and the amount of costs that are fixed in for the relevant production range (i.e., not increased following the production change).

[92] In our simulations, perhaps in contrast, daily/periodical net growth on the standing biomass is likely to be highest with lower average fish weight because of decreasing relative growth with increasing fish weight. The effect of sea lice on growth and mortality is not incorporated into our simulation.

[93] See kyst.no, 2017^{d} for an example.

8.4 Areas for further research

In terms of future research, topics of interest with respect to land based aquaculture of salmon include a wide range of issues such as stochastic risk analysis of production and production economy as noted above, the management of fish health, biological needs and water quality in land based aquaculture systems, technological solutions, market and marketing opportunities and environmental impacts. In terms of marketing, outcomes likely depend both on consumer trends and concerns as well as the extent to which land based production proves able to control the aquaculture environment and provide a chemical and disease free, sustainable/local/healthy product with a limited footprint – while convincing consumers that they do so.

Many of the relevant research questions may well rely on conducting actual grow-out trials and building experience with the opportunities and challenges of producing salmon using this technology. Focus points noted by the industry include challenges such as early maturation of fish, smoltification and choice of water sources and water quality parameters, light regime, solutions for biosecurity and bacterial culture – for instance how many RAS units to have in a facility and the trade-offs between biosecurity and cost of equipment and production, solutions for fish handling, fish densities and water quality, feed quality and feed distribution system (feed dust and particles in the water, etc.), off-flavour – purging procedure and duration, and questions such as the design and size features appropriate for fish tanks (Olsen, 2017).

A number of areas for future research also relate to the increasing variety of smolt size. Many questions relate to the interactions between technology and biology. It might be considered whether such a discussion should be included in the summary of an economic research – but associated with most of the questions are at least often economic tradeoffs. For instance, a central question related to the level of investments is the chosen level of salinity – fresh water, brackish water or salt water (industry source, personal communication). This in turn has implications for the level of technological equipment and for fish biology[94]. This is just one example. As discussed briefly under land based grow-out, many other questions are

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[94] With respect to biology, the smoltification process of salmon – where the fish naturally adapt from a fresh water environment to a salt water environment – relies very much on salinity and has important implications for the general development of the fish (ibid). When the fish are held on land rather than released to sea following the smoltification process, this involves new questions in relation to optimal water conditions, timing and smoltification. For now, industry practice seems to include both fresh water production and mixing of water sources, allowing imitation of the smolts' natural adaptation process – with smoltification and increasing salinity starting already from when the salmon is 40-45 g (industry source). The former option (fresh water) allows investments to be kept at a lower level, as technology and equipment for fresh water are less demanding. However, in terms of biology this may involve delayed smoltification or de-smoltification, with potential/unknown impacts on fish health, growth and development. The latter option, with increasing salinity and imitation of the natural smoltification process, may require larger investments in order to step up the level and quality of equipment (such as pumps, etc). On the other hand, the fish tend to go through a rapid growth phase following the smoltification process, which should be realised and maintained under this approach (ibid).

relevant also here, including optimal fish densities, tank layout and water turbidity, water chemistry, fish handling, etc. Vaccination strategy is also of relevance in both cases; normally fish are vaccinated before saltwater adaptation due to exposure to transmittable diseases, etc. from uncontrolled and unsterilised water. Gains from vaccination in terms of fish health and disease outbreaks are substantial – but it has also been indicated that vaccination has by effects, particularly when the fish are small. In the production of larger smolt on land, more flexibility may be realised in the selection of an optimal vaccination time[95].

The market for smolts could also be an interesting topic – including prices, transfer prices, vaccination strategies and more. If most companies already have integrated smolt supply, analyses with the perspective of integrated firms might be most relevant. As emphasised, motivation for investment in post smolt extends beyond the outcomes from smolt production itself – and to its role and impact on the overall company performance. Looking at the sea based production phase, a question of great interest from both a biological and economic point of view is the optimal point in time (and fish size) for release to sea. This depends both on the cost of production on land versus sea, as well as relevant "bottlenecks", such as sea based production permissions and MTB at various levels.

How companies approach the MTB utilisation problem with and without post smolt seems to be another interesting topic for further research, as discussed at length in chapter VI. The current study analysed the effects of a transition from 100-g smolt to 410-g smolt, attempting to reveal how production quantity would be affected by such a transition. However, the analysis concentrated on company-level MTB, assuming that this limit would determine harvest, and that location-MTB was sufficient enough not to become binding. An interesting extension could be to look at constraints at both levels. This could be done by simulations as well as by examining how companies actually adapt their production plans from their former ones when introducing larger smolts. Questions include what their current constraints to MTB utilisation are and how they use post smolt to address such constraints. That way, it could also be shed light on how different production strategies vary in terms of sea based production risk and approach to environmental and other concerns.

Whether or not the importance of having approximately the maximum permitted biomass in sea at all times could conflict with concerns over and efforts towards enhancing

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[95] For more rigorous analyses of the biology of smolt production, it is referred to (for instance) Nofima. Biological details and literature has not been studied in depth for the purpose of this study, so the questions and information presented in this section are based on personal communication with the industry, observation of topics discussed at conferences and variations in solutions and technologies observed under collection of information and data.

biosecurity should be of interest for future research. Likewise, the ways in which MTB-utilisation strategies may influence and be influenced by concerns over biosecurity should be of interest. One such question is whether company-MTB on the one hand – and initiatives in the form coordination within zonal regions on the other hand – impose conflicting restrictions and incentives. In the worst case, this might involve unintended penalties for biosecurity enhancement and rewards for maintaining a most possibly continuous production if or when the two objectives conflict. Given the nature, accumulation and dissemination of transmittable diseases and parasites such as sea lice, the questions seem relevant (Morency-Lavoie, 2016).

In general, it seems as if there could be much to learn about both current Norwegian industry regulations and how they impose incentives upon companies and impact firm behaviour. Such effects are likely hard both to assess and predict, so comparative studies between different regulatory regimes both in the same country (i.e., over time) and among countries seem of great interest. With respect to MTB, questions have also been raised about if or how the regulations in Norway impact different firms differently. It was noted that smaller, geographically concentrated and less flexible producers may suffer penalties in terms of license utilisation under efforts to coordinate fallowing in general and/or within production zones (Salmon Group, n.d; Ilaks.no, 2016b). In the context of new regional divisions and regulations ("the traffic light system" as mentioned in chapter II), such possible differences seem highly relevant. Clearly, there are many issues to address. In a Norwegian context, the emergence of unconventional production modes intensifies the need for more knowledge.

Given the sea based biological challenges of today, strengthening sustainability and competitiveness of the conventional industry is important. If alternative regulations and production modes to a greater extent could support prevention rather than treatments, that should be of great interest for both industry and government[96]. Of course, this is a very complicated matter with wide ranging impacts in many areas, but nonetheless, the timing seems right for a dialogue about how regulations best can support biological sustainability in the industry. Consequently, there are many challenges for future research.

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[96] As they say in the Faroes, "treatment is a short-term solution to a long-term problem" (Atli Gregersen, in Østergård, 2016).

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APPENDIX A: BACKGROUND

Note A1: Environmental concerns

The simple constructions of sea-based net pens are vulnerable to storms and bad weather. Salmon escapes do happen, and many concerns have been voiced about genetic erosion in wild salmon stocks after farmed fish escape and mate with wild individuals (Science for Environment Policy 2015). The controversial short-term effects of escaped salmon include competition and breeding with wild salmon, the spreading of diseases and parasites to wild salmon and hybridisation with trout (Asche & Bjørndal, op. cit).

In recent years, better equipment standards and improved management of the escapee problem have substantially reduced the number of escapees despite substantial increases in production. As illustrated in figure A1, after peaking at 920 thousand escapees in 2006, the number of escapees has since remained below 364 thousand (varying from 38 thousand in 2012 to 364 thousand in 2011). Nevertheless, the absolute figures should be treated with caution. In addition to incentives to under-report as a consequence of negative publicity and potential lawsuits, farmers may in some cases be unaware of escapees if damages to the nets are detected too late, or if uncertainty exists as to how many fish are present in the cages (ibid.). Yet, under-reporting is not likely to undermine the main trends.

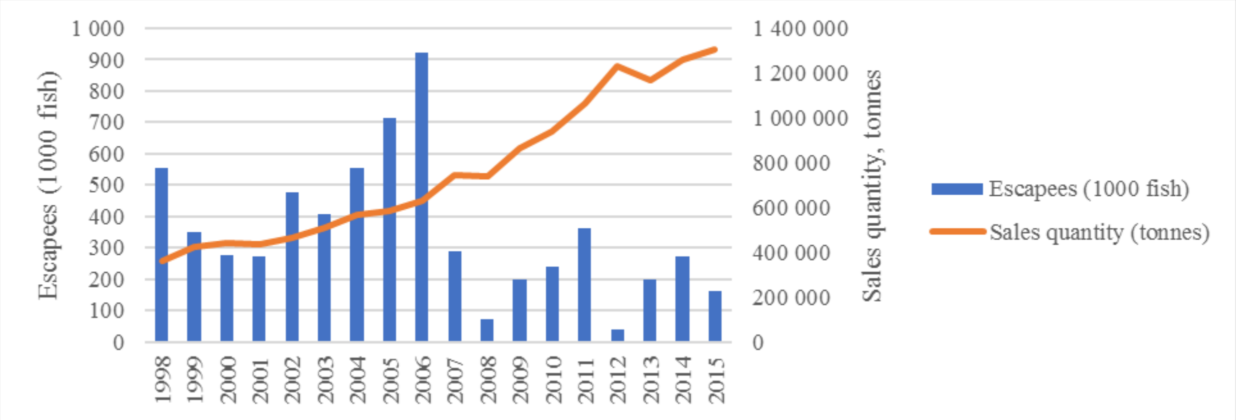

Figure A1: Number of escaped salmon (1000 fish) and total Norwegian sales of farmed salmon (tonnes). 1998-2015.
Source: The Norwegian Directorate of Fisheries

Organic waste, stemming primarily from fish feces and feed waste, account for most of the pollution around fish farms. Organic waste may accumulate and contaminate the seabed around the farm and thereby causing damage to the local fauna (Asche & Bjørndal, op.cit). The consequences of waste accumulation not only pose a challenge to the natural habitat, but also impose negative feedback on productivity at the aquaculture production site through deteriorated biological and growth conditions for the fish. Salmon farmers have responded to these problems in several ways. Improved feed and feeding technology has led to a decline in the feed conversion ratio (FCR) from almost 3 kg of feed required to produce 1 kg of salmon in 1995 (ibid.), to 1.23 kg in 2015 (The Norwegian Directorate of Fisheries, 2016). During the past two decades, the feed conversion ratio has remained relatively stable over time (figure A2). Furthermore, most salmon farms are now located in areas with relatively strong currents, deep water and suitable seabed topography, which reduces the accumulation of waste sediments. Consequently, while the production quantity has increased substantially over the past decades, the organic waste per kg of salmon produced is likely to have declined.

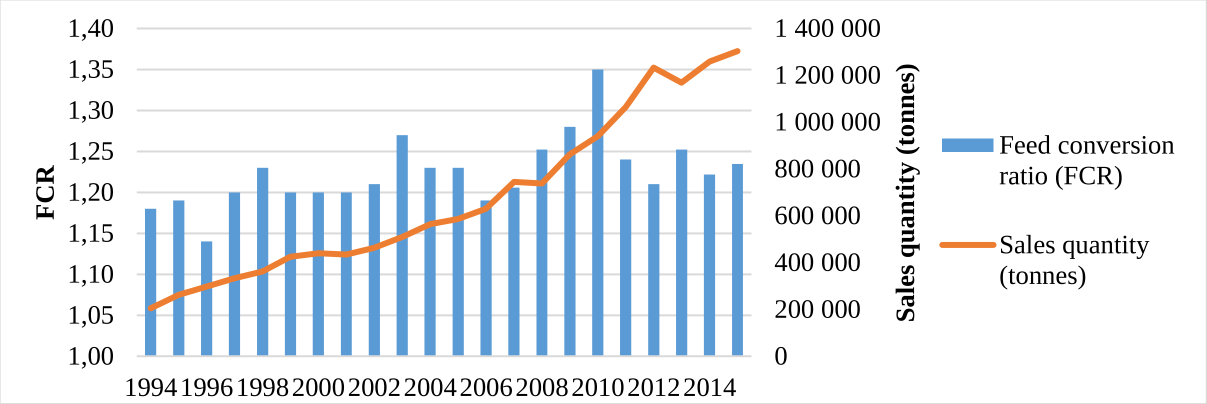

Figure A2: Feed conversion ratio (FCR) and total Norwegian sales of farmed salmon (tonnes). 1994-2015.
Source: The Norwegian Directorate of Fisheries

The use of antibiotics was extensive in salmon aquaculture during the 1980s and became a controversial issue concerning the environmental and health impacts of the industry's practices, provoking much criticism from consumers (Asche & Bjørndal, op.cit). Since then, as demonstrated by figure A3, the use of antibiotics has been virtually eliminated from Norwegian aquaculture due to the development and use of vaccines (ibid.).

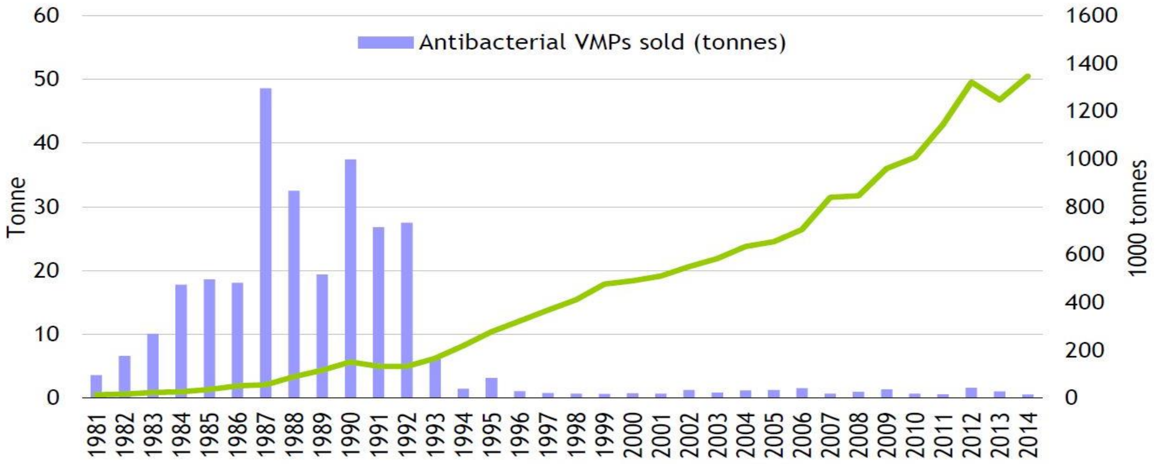

Figure A3: The use of antibiotic/antimicrobial veterinary medicinal products (VMPs) in Norwegian aquaculture compared to harvested biomass. 1981-2014.
Source: Grave & Brun, 2016.

Note A2: Regulations

In 1981, the first permanent aquaculture law was established (Bjørndal, 1987). Objectives included maintaining a small-scale, owner-operated industry structure, generating employment in rural districts, controlling influence on the local environment and ensuring profitability, for instance by adapting the total production to market demand (ibid.). The types of regulations imposed on salmon grow out production can be summarised as follows: 1) regulation of entry (licenses), 2) location of sites, 3) the size of sites (production volume), 4) factor inputs (fingerling release), 5) structure of ownership and 6) transfer of ownership (Bjørndal, *op.cit*).

1991 was a turning point for the industry. The late 1980s and early 1990s had seen major and increasing financial difficulties (Asche & Bjørndal, *op.cit*). Increasing supply including a considerable increase in catches of wild salmon caused prices and profit margins to fall as illustrated in figure 2.1, and considerable losses due to disease magnified the problems. Not only did many farms face bankruptcy, so did the Fish Famers' Sales Organisation (FOS), the organisation that hitherto had been responsible for all first-hand transaction s of salmon and trout (Asche & Bjørndal, *op.cit*). The government replied to the financial crisis by a major liberalisation of the regulation regime, most importantly allowing companies to own more than only one production licence per firm and allowing licenses to be sold in the market (ibid; Liu et. al, 2010). As ownership regulations were abolished, firms started to merge and combine licenses (Asche & Bjørndal, *op.cit*). Throughout the 1990s, mergers and more efficient allocation of production licences led to a reduction in the number of locations, while the production per location increased (ibid). Economies of scale was achieved by expanding farm size, implying that the former regulatory regime had inhibited the industry from reaching the minimum efficient scale, the size of production where all potential benefits from increasing scale are realised. The changes contributed to ownership concentration and greater acceptance of outside ownership in the industry (Stikholmen, *op.cit*).

In 1995, trade conflicts and dumping claims by the EU led to the implementation of a new production system of feeding quotas, where the production quantity was limited by controlling the quantities of feed that could be used per licence (Asche & Bjørndal, op.cit, 36). The system remained in place from 1996-2003. The current MTB regime has been in operation since 2005.

Table A1. Cost of production. NOK/smolt.

	2008	2009	2010	2011	2012	2013	2014	2015
Roe/fingerling	1,53	1,37	1,59	1,50	1,66	1,60	1,78	1,73
Feed	0,92	0,99	1,02	1,11	1,13	1,34	1,38	1,50
Insurance	0,12	0,12	0,11	0,11	0,11	0,10	0,10	0,10
Vaccines	1,26	1,31	1,21	1,27	1,37	1,12	1,11	1,16
Labour	1,59	1,73	1,72	1,77	1,67	1,62	1,64	1,66
Depreciation	0,61	0,76	0,78	0,82	0,86	1,02	1,01	1,11
Electricity	0,43	0,44	0,51	0,53	0,45	0,51	0,49	0,45
Other operating costs	1,93	1,79	1,71	2,18	1,95	1,92	2,02	2,35
Finance cost	0,34	0,40	0,35	0,38	0,34	0,40	0,30	0,30
Cost of production per smolt	**8,73**	**8,92**	**9,01**	**9,66**	**9,53**	**9,61**	**9,83**	**10,38**

Table A2. Cost of production and cost shares, 2008 and 2015. NOK/smolt and cost shares in percent.

	2008	Cost share (2008)	2015	Cost share (2015)
Roe/fingerling	1,53	18 %	1,73	17 %
Feed	0,92	11 %	1,50	14 %
Insurance	0,12	1 %	0,10	1 %
Vaccines	1,26	14 %	1,16	11 %
Labour	1,59	18 %	1,66	16 %
Depreciation	0,61	7 %	1,11	11 %
Electricity	0,43	5 %	0,45	4 %
Other operating costs	1,93	22 %	2,35	23 %
Finance cost	0,34	4 %	0,30	3 %
Cost of production per smolt	**8,73**	**100 %**	**10,38**	**100 %**

APPENDIX B. BIOLOGICAL MEASURE

Note B1: The thermal growth coefficient (TGC)

Much of the biological input on fish growth is based on growth coefficients obtained from Nofima, a research institute. Forecasting fish growth is complex as it is influenced by many factors. The endogenous factors that are controlled by the manager at the fish plant include stocking density, the number of juveniles released, the feeding pattern and the type of feed (Braaten Thyholdt, 2014). If managers control these factors equally well, variations in the grow-out period mainly results from the effects of exogenous biophysical factors on salmon production such as sea temperature, currents, disease outbreaks and daylight hours[97] (ibid.). In particular, fish are highly reliant on temperature, and the variation in sea temperature is considered to be the most important biophysical factor that influences salmon growth, provided that sufficient feed and oxygen is present (ibid.). For net-pen producers these factors are mostly outside of the farmers' influence, whereas land based farmers may to a larger extent be able to adapt the production environment to achieve beneficial conditions with respect to temperature, daylight hours and currents. This analysis will not model any of these factors, but presents assumptions about temperature along with other data in chapters IV and V.

There are several means of calculating growth in salmon, one of which is the Growth Factor 3 (Norwegian, Vekstfaktor VF3), internationally known as the thermal growth coefficient (TGC). After the specific growth rate (SGR), another well-known growth measure, the TGC is perhaps the most widely used growth coefficient in aquaculture (Iversen & Kosmo, 2004; Jobling, 2003). The SGR, however, does not adjust for temperature or size differences. As the TGC is relatively stable over large parts of the life cycle and within the usual temperature range for salmon, the measure made it easier to compare productivity among fish groups and across temperatures and is appropriate to use for forecasting growth (ibid.). A benefit of the measure is that it represents a simple exponential formula that takes account both of the temperature and fish size without relying on laborious calculations to account for different (decreasing) daily growth rates for different (increasing) sizes of fish (Holmefjord et. al, 1994).

The TGC looks at growth directly in relation to the temperature sum and is expressed as:

$$TGC = \frac{(Final\ weight^{\frac{1}{3}} - Start\ weight^{\frac{1}{3}}) * 1000}{Day\ degrees},$$

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[97] Daylight hours may be controlled through the use of artificial light.

where day degrees (or the temperature sum) is the temperature in degrees Celsius times the total number of growth days. This temperature sum can be calculated by either summing every single temperature reading or taking the average temperature for each month and multiplying these by the number of days in each month (ibid.). The TGCs used for forecasting in this study are obtained from Nofima and from published sources (Austreng et. al., 1987; Thorarensen & Farrell, 2011) and are to be presented later. The formula for calculating growth using TGC is expressed as:

$$Final\ weight = (Start\ weight^{\frac{1}{3}} + TGC * \frac{Day\ degrees}{1000})^3$$

The model assumes that the TGC coefficient is independent of fish size and temperature. Some research has indicated that the maximum difference in predicted TGC is 6% (between 50 g fish at 4 °C and 3000 g fish at 14 °C) and the maximum difference in TGC for the same-sized fish reared at either 4 or 14 °C is 4% (Chadwick et. al, 2010; Thorarensen & Farrell, 2011). Hence, the model should hold fairly well within the relevant temperature range.

The temperatures assumptions in this study are as follows: 12 degrees Celsius in land based facilities (after a smolt size of 92 g) and in sea as given below in tables B1a and b.

Table B1a: General assumptions about average sea temperature. Temperatures measured at a depth of 5 m at the research station of Bud, Norway. 2006-2016 (with lots of missing data).

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Average temperature**	**Number of obs. 2006-2016**
Jan	6,528			6,08				5,407				6,0	3
Feb	6,552	5,83	5,727			4,483		4,159	5,868		6,544	5,6	7
Mar	5,535	6,487	5,37	5,39			6,119	3,723	5,661	6,012	5,93	5,6	9
Apr	5,68		6,071	6,145	4,92	5,01		3,943			6,494	5,5	7
May	6,66	7,64	8,415	10,293	6,243	6,993	8,335	6,076	7,398	7,352	8,461	7,6	11
Jun	9,703	9,267	10,373	12,475	9,513	9,21		11,317			8,954	10,1	8
Jul	13,706	12,23	13,082		11,717							12,7	4
Aug	15,509	13,997	16,331	15,72		9,28	14,387		14,928	14,3		14,3	8
Sep	14,751	10,89	15,312		14,01		12,358		14,857	13,869	15,064	13,9	8
Oct	14,25	10,297		10,455		11,319	11,308		12,245		12,552	11,8	7
Nov	9,227	8,228	9,74	9,204	8,36	10,547			10,193			9,4	7
Dec		7,387	7,695	8,405					8,987		7,939	8,1	5

Source: imr.no

Table B1b: Average sea temperature profile based on table 1a.

	Sea temperature
Jan	6,0
Feb	5,6
Mar	5,6
Apr	5,5
May	7,6
Jun	10,1
Jul	12,7
Aug	14,3
Sept	13,9
Oct	11,8
Nov	9,4
Dec	8,1

APPENDIX C: MAIN ANALYSES AND PRODUCTION PLANS

Table C1a: Production plan for a land based facility with an annual production capacity of 5,000 tonnes. Monthly development for a single release, from individual fish sizes of 0.2 g in month 0 – until harvest throughout month 18.

Month (beginning)	Weight (g) per fish, w_t	Weight (g) increase, w_{t+1} - w_t	Survival %	Number of fish (given survival rate), N_t	Total biomass weight increase (kg), incl. mortality, ((w_t+1 - w_t)*N_t)/1,000	Biomass weight (kg), $B_t = N_t w_t$/1,000	Biological feed conversion ratio, FCR:	Feed quantity (kg) per month FCR x Total biomass weight increase (kg), incl. mortality	Feed cost (NOK) per month
0	0,2	1	0,960	102 150	61	20	0,9	55	772 kr
1	0,8	2	0,995	98 064	226	78	0,9	203	2 842 kr
2	3,1	5	0,995	97 574	478	302	0,9	430	6 024 kr
3	8	16	0,995	97 086	1 553	777	0,9	1 398	19 572 kr
4	24	26	0,995	96 600	2 512	2 318	0,9	2 260	31 646 kr
5	50	42	0,995	96 117	4 037	4 806	0,9	3 633	50 865 kr
6	92	73	0,995	95 637	6 995	8 799	0,9	6 295	88 135 kr
7	165	104	0,995	95 159	9 919	15 714	0,9	8 927	124 984 kr
8	269	141	0,995	94 683	13 336	25 506	0,9	12 003	168 036 kr
9	410	183	0,995	94 209	17 238	38 648	0,9	15 514	217 194 kr
10	593	231	0,995	93 738	21 616	55 606	0,9	19 455	272 365 kr
11	824	284	0,995	93 270	26 465	76 836	0,9	23 818	333 454 kr
12	1 108	342	0,995	92 803	31 775	102 784	1,1	34 953	489 338 kr
13	1 450	407	0,995	92 339	37 541	133 886	1,1	41 295	578 129 kr
14	1 856	476	0,995	91 878	43 754	170 570	1,1	48 130	673 816 kr
15	2 333	551	0,995	91 418	50 408	213 253	1,1	55 449	776 289 kr
16	2 884	632	0,995	90 961	57 496	262 343	1,1	63 246	885 439 kr
17	3 516	718	0,995	90 506	65 010	318 240	1,1	71 511	1 001 157 kr
18	4 235	810	0,995	90 054	36 381	208 381	1,1	40 019	560 265 kr
19	5 045	-	0,995	89 604		-			

Table C1b: Harvest, feed and feed cost per month and per year, given the production plan as outlined in table C1a

Harvest is 22 tonnes x 19 working days in month 18:

Total harvest from a single release is the average weight per fish in month 18 times the average number of fish throughout month 18:	416,8	tonnes
Harvest per day over 19 working days:	21,93	tonnes
Harvest per year:	5001,14	tonnes
Feed per month (tonnes):	448,6	tonnes
Feed per year (tonnes):	5 383,1	tonnes
Feed cost per month (NOK)	6 280 324	NOK
Feed cost per year (NOK)	75 363 888	NOK
Economic FCR:	1,08	

Table C2: Production plan for a land based facility with an annual production capacity of 1,600 tonnes. Monthly development for a single release, from individual fish sizes of 0.2 g in month 0 – until release to sea after month 8.

Month (1st)	Weight (g) per fish, w_t	Weight (g) increase, $w_{t+1} - w_t$	Survival %	Number of fish	Total biomass weight increase (kg), incl. mortality	Biological feed conversion ratio, FCR:	Feed quantity (kg) = FCR x total biomass weight increase (kg)	Feed cost (NOK)
0	0,2	0,6	0,960	1 084 287	672	0,90	605	9 075
1	0,8	2,3	0,995	1 040 915	2 394	0,90	2 155	32 320
2	3,1	4,9	0,995	1 035 711	5 075	0,90	4 567	68 512
3	8,0	16,0	0,995	1 030 532	16 489	0,90	14 840	222 595
4	24,0	26,0	0,995	1 025 379	26 660	0,90	23 994	359 908
5	50,0	42,0	0,995	1 020 253	42 851	0,90	38 566	578 483
6	92,0	73,1	0,995	1 015 151	74 248	0,90	66 823	1 002 350
7	165,1	104,2	0,995	1 010 076	105 291	0,90	94 762	1 421 426
8	269,4	140,9	0,995	1 005 025	141 559	0,90	127 403	1 911 045
9	410,2			1 000 000	0		-	
						SUM:	**373 714**	**5 605 715**
						Economic FCR:	0,91	

Hatcery survival rate:	0,9	Price per kg of feed:	15
Number of roe purchases:	4	Price per egg	1
Egg quantity per batch of roe	120 4763		

Table C3: Investment and reinvestment used to estimate terminal value of investment, chapter IV:

Investment and reinvestment	
Year 20	398558
Year 29	6 011
Year 40	398558
Year 49	6 011
Year 60	398558

Table C4: 410-g grow-out. Average production time from release until harvest of 5-kg salmon. Estimated based on four annual releases in December, March, June and September

Month	December	March	June	Sept	**Average**
0	410	410	410	410	**410**
1	479	473	565	553	**517**
2	567	594	837	720	**680**
3	665	785	1174	890	**879**
4	772	1078	1522	1032	**1101**
5	939	1486	1843	1177	**1361**
6	1194	1970	2155	1335	**1664**
7	1576	2455	2408	1502	**1985**
8	2095	2893	2660	1759	**2352**
9	2697	3310	2929	2141	**2769**
10	3291	3645	3209	2695	**3210**
11	3820	3976	3630	3426	**3713**
12	4320	4327	4241	4252	**4285**
13	4719	4689	5101	5048	**4889**
14	5112	5227		5747	**5362**

Table C5a: Production time from release to harvest, 100-g smolts. Releases in May and October (as illustrated in the text, figure 6.1).

Month	Weight (g) per fish	
(beginning)	May	October
0	100	100
1	150	145
2	254	207
3	421	262
4	640	322
5	877	390
6	1103	465
7	1326	585
8	1510	775
9	1696	1065
10	1896	1470
11	2107	1951
12	2427	2433
13	2897	2867
14	3570	3282
15	4445	3615
16	5421	3945
17		4294
18		4923

The production time for grow-out of 100-g smolts released in the remaining months of a year is given below in table C4b.

Table C5b: Weight development in grams per fish by month of release to sea (smolt, 100 g). January – December.

Month	January	February	March	April	May	June	July	August	Sept	October	November	December
0	100	100	100	100	100	100	100	100	100	100	100	100
1	126	126	125	136	150	164	174	172	159	145	139	128
2	163	162	177	212	254	292	302	276	236	207	181	166
3	206	224	267	342	421	468	450	384	319	262	229	210
4	278	327	416	541	640	662	597	498	392	322	283	260
5	396	496	641	798	877	850	748	595	469	390	344	344
6	586	747	927	1070	1103	1039	875	697	556	465	444	479
7	865	1061	1226	1326	1326	1196	1005	809	651	585	602	693
8	1209	1387	1505	1577	1510	1356	1147	929	800	775	850	1002
9	1563	1690	1778	1783	1696	1529	1299	1117	1031	1065	1202	1380
10	1890	1984	2001	1991	1896	1712	1532	1403	1378	1470	1625	1766
11	2207	2224	2225	2213	2107	1991	1882	1826	1855	1951	2053	2119
12	2463	2463	2464	2447	2427	2406	2393	2396	2413	2433	2443	2460
13	2720	2719	2715	2799	2897	3002	3070	3052	2965	2867	2817	2736
14	2993	2986	3092	3315	3570	3786	3839	3695	3460	3282	3118	3010
15	3277	3387	3642	4049	4445	4666	4585	4265	3929	3615	3417	3302
16	3703	3971	4422	4998	5421	5512	5241	4803	4303	3945	3734	3605
17	**4322**	**4796**	**5426**	**6050**	**6353**	**6252**	**5856**	**5231**	**4673**	**4294**	**4063**	**4059**
18	**5193**	**5854**	**6536**	**7051**	**7166**	**6942**	**6343**	**5651**	**5063**	**4654**	**4553**	**4716**
19	6306	7020	7588	7921	7921	7487	6821	6092	5464	5190	5262	5637

Table C6: Weight development in grams per fish by month of release to sea (post smolt, 410 g). January – December.

Month	January	February	March	April	May	June	July	August	Sept	October	November	December
0	410	410	410	410	410	410	410	410	410	410	410	410
1	474	474	473	499	531	565	587	581	553	521	505	479
2	562	559	594	670	759	837	857	804	720	659	603	567
3	657	695	785	935	1087	1174	1142	1017	890	776	705	665
4	807	906	1078	1308	1484	1522	1409	1229	1032	896	818	772
5	1039	1226	1486	1755	1889	1843	1670	1404	1177	1028	940	939
6	1389	1669	1970	2205	2258	2155	1884	1582	1335	1169	1130	1194
7	1868	2190	2455	2613	2613	2408	2099	1773	1502	1387	1417	1576
8	2428	2709	2893	3003	2900	2660	2329	1975	1759	1716	1843	2095
9	2982	3176	3310	3318	3185	2929	2571	2281	2141	2196	2416	2697
10	3478	3619	3645	3629	3488	3209	2934	2734	2695	2838	3076	3291
11	3949	3974	3976	3959	3802	3630	3467	3381	3426	3569	3722	3820
12	4325	4325	4327	4301	4271	4241	4222	4227	4252	4280	4295	4320
13	**4696**	**4695**	**4689**	**4810**	**4951**	**5101**	**5197**	**5172**	**5048**	**4908**	**4836**	**4719**
14	5087	5078	5227	5543	5901	6202	6276	6076	5747	5497	5265	5112

Table C7: The simulation model using 410-gram smolt. Weight per fish at each location, survival rate, number of fish per location, total biomass and MTB balance and harvest in number of fish per location.

Month (IB)	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**		**Release per l**	**Mortality**	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**	**IB biomass**	**SUM Net growth forecast current month**	**Target IB biomass = MTB - net growth forecast**	**IB biomass balance**	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**		**Harvest, number of fish**	**Harvesr at UB weight**
	Weight per fish (kg)									Number of fish (IB = IB Survived fish after last month - harvest previous month)										Harvest (number)								
																				0	0	0	0	0	0			
Mar	0,410							*500 000*	***0,75 %***	500 000						205 000	29 567	3 090 433	2 885 433	0	0	0	0	0	0		0	0
Apr	0,473									496 250						234 567	58 116	3 061 884	2 827 317	0	0	0	0	0	0		0	0
May	0,594									492 528						292 683	91 140	3 028 860	2 736 176	0	0	0	0	0	0		0	0
Jun	0,785									488 834						383 824	139 091	2 980 909	2 597 085	0	0	0	0	0	0		0	0
Jul	1,078	0,410								485 168	500 000					727 915	279 015	2 840 985	2 113 070	0	0	0	0	0	0		0	0
Aug	1,486	0,587								481 529	496 250					1 006 930	356 791	2 763 209	1 756 279	0	0	0	0	0	0		0	0
Sept	1,970	0,857								477 918	492 528					1 363 721	359 011	2 760 989	1 397 267	0	0	0	0	0	0		0	0
Oct	2,455	1,142								474 333	488 834					1 722 733	322 503	2 797 497	1 074 765	0	0	0	0	0	0		0	0
Nov	2,893	1,409	0,410							470 776	485 168	500 000				2 250 235	351 099	2 768 901	518 666	0	0	0	0	0	0		0	0
Dec	3,310	1,670	0,505							467 245	481 529	496 250				2 601 334	286 400	2 833 600	232 266	12 870	0	0	0	0	0		12 870	46 909
Jan	3,645	1,884	0,603							450 871	477 918	492 528				2 840 826	279 117	2 840 883	57	68 800	0	0	0	0	0		68 800	273 574
Feb	3,976	2,099	0,705							378 689	474 333	488 834				2 846 369	273 507	2 846 493	124	111 250	0	0	0	0	0		111 250	481 328
Mar	4,327	2,329	0,818	0,410						264 599	470 776	485 168	500 000			2 843 547	276 335	2 843 665	118	84 000	0	0	0	0	0		84 000	393 867
Apr	4,689	2,571	0,940	0,473						178 614	467 245	481 529	496 250			2 726 015	393 935	2 726 065	50	98 660	0	0	0	0	0		98 660	515 725
May	5,227	2,934	1,130	0,594						78 615	463 741	477 918	492 528			2 604 225	515 768	2 604 232	8	78 025	47 500	0	0	0	0		125 525	632 981
Jun	6,002	3,467	1,417	0,785						0	412 763	474 333	488 834			2 487 012	632 948	2 487 052	40	0	218 880	0	0	0	0		218 880	924 062
Jul	7,079	4,222	1,843	1,078	0,410					0	190 787	470 776	485 168	500 000		2 400 897	719 005	2 400 995	97	0	136 440	0	0	0	0		136 440	709 017
Aug	8,439	5,197	2,416	1,486	0,587					0	52 916	467 245	481 529	496 250		2 410 885	709 063	2 410 937	52	0	52 519	85 510	0	0	0		138 029	592 665
Sept		6,276	3,076	1,970	0,857					0	0	378 231	477 918	492 528		2 527 281	592 714	2 527 286	5	0	0	123 300	0	0	0		123 300	458 937
Oct		7,301	3,722	2,455	1,142						0	252 094	474 333	488 834		2 661 057	458 892	2 661 108	51	0	0	142 150	0	0	0		142 150	610 585
Nov		8,191	4,295	2,893	1,409	0,410					0	108 053	470 776	485 168	500 000	2 714 364	405 547	2 714 453	89	0	0	62 800	0	0	0		62 800	303 671
Dec		9,015	4,836	3,310	1,670	0,505					0	44 443	467 245	481 529	496 250	2 816 240	303 728	2 816 272	32	0	0	44 109	12 870	0	0		56 979	279 139
Jan			5,265	3,645	1,884	0,603					0	0	450 871	477 918	492 528	2 840 828	279 117	2 840 883	54	0	0	0	68 800	0	0		68 800	273 574
Feb			5,687	3,976	2,099	0,705						0	378 689	474 333	488 834	2 846 372	273 507	2 846 493	122	0	0	0	111 250	0	0		111 250	481 328
Mar	0,410		6,130	4,327	2,329	0,818				500 000		0	264 599	470 776	485 168	2 843 550	276 335	2 843 665	114	0	0	0	84 000	0	0		84 000	393 867
Apr	0,473		6,586	4,689	2,571	0,940				496 250		0	178 614	467 245	481 529	2 726 018	393 935	2 726 065	47	0	0	0	98 660	0	0		98 660	515 725
May	0,594			5,227	2,934	1,130				492 528		0	78 615	463 741	477 918	2 604 225	515 768	2 604 232	8	0	0	0	78 025	47 500	0		125 525	632 981
Jun	0,785			6,002	3,467	1,417				488 834			0	412 763	474 333	2 487 012	632 948	2 487 052	40	0	0	0	0	218 880	0		218 880	924 062
Jul	1,078	0,410		7,079	4,222	1,843				485 168	500 000		0	190 787	470 776	2 400 897	719 005	2 400 995	97	0	0	0	0	136 440	0		136 440	709 017
Aug	1,486	0,587		8,439	5,197	2,416				481 529	496 250		0	52 916	467 245	2 410 885	709 063	2 410 937	52	0	0	0	0	52 519	85 510		138 029	592 665
Sept	1,970	0,857			6,276	3,076				477 918	492 528		0	0	378 231	2 527 281	592 714	2 527 286	5	0	0	0	0	0	123 300		123 300	458 937
Oct	2,455	1,142			7,301	3,722				474 333	488 834			0	252 094	2 661 057	458 892	2 661 108	51	0	0	0	0	0	142 150		142 150	610 585
Nov	2,893	1,409	0,410		8,191	4,295				470 776	485 168	500 000		0	108 053	2 714 364	405 547	2 714 453	89	0	0	0	0	0	62 800		62 800	303 671
Dec	3,310	1,670	0,505		9,015	4,836				467 245	481 529	496 250		0	44 443	2 816 240	303 728	2 816 272	32	12 870	0	0	0	0	44 109		56 979	279 139
Jan	3,645	1,884	0,603			5,265				450 871	477 918	492 528		0	0	2 840 828	279 117	2 840 883	54	68 800	0	0	0	0	0		68 800	273 574
Feb	3,976	2,099	0,705			5,687				378 689	474 333	488 834			0	2 846 372	273 507	2 846 493	122	111 250	0	0	0	0	0		111 250	481 328
Mar	4,327	2,329	0,818	0,410		6,130				264 599	470 776	485 168	500 000		0	2 843 550	276 335	2 843 665	114	84 000	0	0	0	0	0		84 000	393 867
Apr	4,689	2,571	0,940	0,473		6,586				178 614	467 245	481 529	496 250		0	2 726 018	393 935	2 726 065	47	98 660	0	0	0	0	0		98 660	515 725
May	5,227	2,934	1,130	0,594						78 615	463 741	477 918	492 528		0	2 604 225	515 768	2 604 232	8	78 025	47 500	0	0	0	0		125 525	632 981
Jun	6,002	3,467	1,417	0,785						0	412 763	474 333	488 834			2 487 012	632 948	2 487 052	40	0	218 880	0	0	0	0		218 880	924 062
Jul	7,079	4,222	1,843	1,078	0,410					0	190 787	470 776	485 168	500 000		2 400 897	719 005	2 400 995	97	0	136 440	0	0	0	0		136 440	709 017
Aug	8,439	5,197	2,416	1,486	0,587					0	52 916	467 245	481 529	496 250		2 410 885	709 063	2 410 937	52	0	52 519	85 510	0	0	0		138 029	592 665
Sept	0,000	6,276	3,076	1,970	0,857					0	0	378 231	477 918	492 528		2 527 281	592 714	2 527 286	5	0	0	123 300	0	0	0		123 300	458 937
Oct	0,000	7,301	3,722	2,455	1,142						0	252 094	474 333	488 834		2 661 057	458 892	2 661 108	51	0	0	142 150	0	0	0		142 150	610 585
Nov	0,000	8,191	4,295	2,893	1,409	0,410					0	108 053	470 776	485 168	500 000	2 714 364	405 547	2 714 453	89	0	0	62 800	0	0	0		62 800	303 671
Dec	0,000	9,015	4,836	3,310	1,670	0,505					0	44 443	467 245	481 529	496 250	2 816 240	303 728	2 816 272	32	0	0	44 109	12 870	0	0		56 979	279 139
Jan	0,000	0,000	5,265	3,645	1,884	0,603						0	450 871	477 918	492 528	2 840 828	279 117	2 840 883	54	0	0	0	68 800	0	0		68 800	273 574
Feb	0,000	0,000	5,687	3,976	2,099	0,705						0	378 689	474 333	488 834	2 846 372	273 507	2 846 493	122	0	0	0	111 250	0	0		111 250	481 328
Mar	0,410	0,000	6,130	4,327	2,329	0,818				500 000		0	264 599	470 776	485 168	2 843 550	276 335	2 843 665	114	0	0	0	84 000	0	0		84 000	393 867
Apr	0,473	0,000	6,586	4,689	2,571	0,940				496 250		0	178 614	467 245	481 529	2 726 018	393 935	2 726 065	47	0	0	0	98 660	0	0		98 660	515 725
May	0,594	0,000	0,000	5,227	2,934	1,130				492 528			78 615	463 741	477 918	2 604 225	515 768	2 604 232	8	0	0	0	78 025	47 500	0		125 525	632 981
Jun	0,785	0,000	0,000	6,002	3,467	1,417				488 834			0	412 763	474 333	2 487 012	632 948	2 487 052	40	0	0	0	0	218 880	0		218 880	924 062

Table C8: The simulation model using 100-gram smolt. Weight per fish at each location, survival rate, number of fish per location, total biomass and MTB balance and harvest in number of fish per location.

Month (IB)	**Loc. 1**	**Loc. 2**	**Loc. 3**	**Loc. 4**	**Loc. 5**	**Loc. 6**	**Release per**	**Mortality**	**Loc. 1**	**Loc. 2**	**Loc. 3**	**Loc. 4**	**Loc. 5**	**Loc. 6**	**IB biomass**	**Net growth forecast current month**	**Target IB biomass = MTB - net growth forecast**	**IB biomass balance**	**Loc. 1**	**Loc. 2**	**Loc. 3**	**Loc. 4**	**Loc. 5**	**Loc. 6**	**Harvest, number of fish**	**Harvesr at UB weight**
	Weight per fish (kg)								Number of fish (IB = IB Survived fish after last month - harvest previous month)										Harvest (number)							
																			0	0	0	0	0	0		
Mar	0,100						*500 000*	***0,75 %***	500 000						50 000	12 119	3 107 881	3 057 881	0	0	0	0	0	0	0	0
Apr	0,125								496 250						62 119	25 303	3 094 697	3 032 578	0	0	0	0	0	0	0	0
May	0,177								492 528						87 422	43 027	3 076 973	2 989 551	0	0	0	0	0	0	0	0
Jun	0,267								488 834						130 449	71 421	3 048 579	2 918 130	0	0	0	0	0	0	0	0
Jul	0,416	0,100							485 168	500 000					251 870	143 507	2 976 493	2 724 623	0	0	0	0	0	0	0	0
Aug	0,641	0,174							481 529	496 250					395 377	196 349	2 923 651	2 528 274	0	0	0	0	0	0	0	0
Sept	0,927	0,302							477 918	492 528					591 726	209 968	2 910 032	2 318 306	0	0	0	0	0	0	0	0
Oct	1,226	0,450							474 333	488 834					801 694	196 926	2 923 074	2 121 380	0	0	0	0	0	0	0	0
Nov	1,505	0,597	0,100						470 776	485 168	500 000				1 048 620	211 291	2 908 709	1 860 089	0	0	0	0	0	0	0	0
Dec	1,778	0,748	0,139						467 245	481 529	496 250				1 259 911	175 634	2 944 366	1 684 455	0	0	0	0	0	0	0	0
Jan	2,001	0,875	0,181						463 741	477 918	492 528				1 435 545	177 097	2 942 903	1 507 358	0	0	0	0	0	0	0	0
Feb	2,225	1,005	0,229						460 263	474 333	488 834				1 612 642	190 646	2 929 354	1 316 712	0	0	0	0	0	0	0	0
Mar	2,464	1,147	0,283	0,100					456 811	470 776	485 168	500 000			1 853 288	212 527	2 907 473	1 054 186	0	0	0	0	0	0	0	0
Apr	2,715	1,299	0,344	0,125					453 385	467 245	481 529	496 250			2 065 814	335 442	2 784 558	718 743	0	0	0	0	0	0	0	0
May	3,092	1,532	0,444	0,177					449 984	463 741	477 918	492 528			2 401 257	507 973	2 612 027	210 771	121 900	0	0	0	0	0	121 900	443 989
Jun	3,642	1,882	0,602	0,267					324 709	460 263	474 333	488 834			2 465 241	654 697	2 465 303	62	179 050	0	0	0	0	0	179 050	791 700
Jul	4,422	2,393	0,850	0,416	0,100				143 224	456 811	470 776	485 168	500 000		2 378 238	741 711	2 378 289	51	134 900	0	0	0	0	0	134 900	731 953
Aug	5,426	3,070	1,202	0,641	0,174				7 250	453 385	467 245	481 529	496 250		2 387 995	731 932	2 388 068	73	7 195	148 200	0	0	0	0	155 395	616 018
Sept	6,536	3,839	1,625	0,927	0,302				0	301 784	463 741	477 918	492 528		2 503 909	616 015	2 503 985	76	0	106 250	0	0	0	0	106 250	487 106
Oct	7,588	4,585	2,053	1,226	0,450				0	193 271	460 263	474 333	488 834		2 632 818	487 135	2 632 865	47	0	91 530	0	0	0	0	91 530	479 716
Nov	8,501	5,241	2,443	1,505	0,597	0,100				100 291	456 811	470 776	485 168	500 000	2 690 234	429 721	2 690 279	45	0	54 850	0	0	0	0	54 850	321 218
Dec		5,856	2,817	1,778	0,748	0,139				44 689	453 385	467 245	481 529	496 250	2 798 736	321 222	2 798 778	42	0	44 354	5 600	0	0	0	49 954	298 812
Jan		6,343	3,118	2,001	0,875	0,181				0	444 384	463 741	477 918	492 528	2 821 146	298 691	2 821 309	163	0	0	85 800	0	0	0	85 800	293 203
Feb		6,821	3,417	2,225	1,005	0,229				0	355 251	460 263	474 333	488 834	2 826 634	293 310	2 826 690	55	0	0	91 200	0	0	0	91 200	340 566
Mar	0,100	7,320	3,734	2,464	1,147	0,283			500 000		261 387	456 811	470 776	485 168	2 829 379	290 537	2 829 463	84	0	0	100 400	0	0	0	100 400	407 945
Apr	0,125		4,063	2,715	1,299	0,344			496 250		159 026	453 385	467 245	481 529	2 711 971	407 973	2 712 027	56	0	0	117 500	0	0	0	117 500	535 030
May	0,177		4,553	3,092	1,532	0,444			492 528		40 334	449 984	463 741	477 918	2 584 914	534 945	2 585 055	141	0	0	40 031	121 900	0	0	161 931	654 617
Jun	0,267		5,262	3,642	1,882	0,602			488 834		0	324 709	460 263	474 333	2 465 242	654 697	2 465 303	61	0	0	0	179 050	0	0	179 050	791 700
Jul	0,416	0,100	6,250	4,422	2,393	0,850			485 168	500 000	0	143 224	456 811	470 776	2 378 240	741 711	2 378 289	49	0	0	0	134 900	0	0	134 900	731 953
Aug	0,641	0,174	7,506	5,426	3,070	1,202			481 529	496 250		7 250	453 385	467 245	2 387 995	731 932	2 388 068	73	0	0	0	7 195	148 200	0	155 395	616 018
Sept	0,927	0,302		6,536	3,839	1,625			477 918	492 528		0	301 784	463 741	2 503 909	616 015	2 503 985	76	0	0	0	0	106 250	0	106 250	487 106
Oct	1,226	0,450		7,588	4,585	2,053			474 333	488 834		0	193 271	460 263	2 632 818	487 135	2 632 865	47	0	0	0	0	91 530	0	91 530	479 716
Nov	1,505	0,597	0,100	8,501	5,241	2,443			470 776	485 168	500 000		100 291	456 811	2 690 234	429 721	2 690 279	45	0	0	0	0	54 850	0	54 850	321 218
Dec	1,778	0,748	0,139		5,856	2,817			467 245	481 529	496 250		44 689	453 385	2 798 736	321 222	2 798 778	42	0	0	0	0	44 354	5 600	49 954	298 812
Jan	2,001	0,875	0,181		6,343	3,118			463 741	477 918	492 528		0	444 384	2 821 146	298 691	2 821 309	163	0	0	0	0	0	85 800	85 800	293 203
Feb	2,225	1,005	0,229		6,821	3,417			460 263	474 333	488 834		0	355 251	2 826 634	293 310	2 826 690	55	0	0	0	0	0	91 200	91 200	340 566
Mar	2,464	1,147	0,283	0,100	7,320	3,734			456 811	470 776	485 168	500 000		261 387	2 829 379	290 537	2 829 463	84	0	0	0	0	0	100 400	100 400	407 945
Apr	2,715	1,299	0,344	0,125		4,063			453 385	467 245	481 529	496 250		159 026	2 711 971	407 973	2 712 027	56	0	0	0	0	0	117 500	117 500	535 030
May	3,092	1,532	0,444	0,177		4,553			449 984	463 741	477 918	492 528		40 334	2 584 914	534 945	2 585 055	141	121 900	0	0	0	0	40 031	161 931	654 617
Jun	3,642	1,882	0,602	0,267		5,262			324 709	460 263	474 333	488 834		0	2 465 242	654 697	2 465 303	61	179 050	0	0	0	0	0	179 050	791 700
Jul	4,422	2,393	0,850	0,416	0,100	6,250			143 224	456 811	470 776	485 168	500 000	0	2 378 240	741 711	2 378 289	49	134 900	0	0	0	0	0	134 900	731 953
Aug	5,426	3,070	1,202	0,641	0,174	7,506			7 250	453 385	467 245	481 529	496 250		2 387 995	731 932	2 388 068	73	7 195	148 200	0	0	0	0	155 395	616 018
Sept	6,536	3,839	1,625	0,927	0,302				0	301 784	463 741	477 918	492 528		2 503 909	616 015	2 503 985	76	0	106 250	0	0	0	0	106 250	487 106
Oct	7,588	4,585	2,053	1,226	0,450				0	193 271	460 263	474 333	488 834		2 632 818	487 135	2 632 865	47	0	91 530	0	0	0	0	91 530	479 716
Nov	8,501	5,241	2,443	1,505	0,597	0,100				100 291	456 811	470 776	485 168	500 000	2 690 234	429 721	2 690 279	45	0	54 850	0	0	0	0	54 850	321 218
Dec	0,000	5,856	2,817	1,778	0,748	0,139				44 689	453 385	467 245	481 529	496 250	2 798 736	321 222	2 798 778	42	0	44 354	5 600	0	0	0	49 954	298 812
Jan	0,000	6,343	3,118	2,001	0,875	0,181				0	444 384	463 741	477 918	492 528	2 821 146	298 691	2 821 309	163	0	0	85 800	0	0	0	85 800	293 203
Feb	0,000	6,821	3,417	2,225	1,005	0,229				0	355 251	460 263	474 333	488 834	2 826 634	293 310	2 826 690	55	0	0	91 200	0	0	0	91 200	340 566
Mar	0,100	7,320	3,734	2,464	1,147	0,283			500 000		261 387	456 811	470 776	485 168	2 829 379	290 537	2 829 463	84	0	0	100 400	0	0	0	100 400	407 945
Apr	0,125	0,000	4,063	2,715	1,299	0,344			496 250		159 026	453 385	467 245	481 529	2 711 971	407 973	2 712 027	56	0	0	117 500	0	0	0	117 500	535 030
May	0,177	0,000	4,553	3,092	1,532	0,444			492 528		40 334	449 984	463 741	477 918	2 584 914	534 945	2 585 055	141	0	0	40 031	121 900	0	0	161 931	654 617