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Viral Diseases in Salmonid Aquaculture

Quantifying economic losses associated with three viral diseases affecting Norwegian salmonid aquaculture

Henrik Vandvik Vedeler

Supervisor: Lassi Ahlvik

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Major in Finance

NORWEGIAN SCHOOL OF ECONOMICS

Table of Contents

Table of Figures

Table of Tables

Preface

This thesis is written as part of my Master of Science in Economics and Business Administration at the Norwegian School of Economics (NHH).

The process of completing this thesis has been both challenging and rewarding. I want to personally thank all companies, institutions and individuals that participated with data, suggestions, ideas, directions and review throughout the preparation of this thesis. I am humbled by the time that has been dedicated to assist my project from companies and individuals across all segments of the salmonid aquaculture value chain.

The Norwegian Directorate of Fisheries (Fiskeridirektoratet) deserves a special mention for their willingness to accept my application for using reported production data from Norwegian salmonid farming sites. This, in my opinion, has greatly increased the validity of the conclusions reached in this study, to a level that would not be possible with a different approach.

The Norwegian Veterinary Institute (Veterinærinstituttet) is also thanked for providing site-level outbreak data for the viral disease Cardiomyopathy Syndrome (CMS).

I would also like to thank my supervisor, Lassi Ahlvik, and Linda Nøstbakken for their insights, guidance and tips throughout the semester.

I sincerely hope the analysis, discussions and conclusions in this thesis can give valuable insights to the salmonid aquaculture industry in Norway and elsewhere. This thesis is hopefully a testament to the benefits of transparency in industries such as the salmonid aquaculture industry, which is highly dependent on support, engagement and involvement from its surrounding environment and stakeholders.

Henrik Vandvik Vedeler

Bergen, Norway

December, 2017

Executive summary

The salmonid aquaculture industry has a unique level of commercialization and technological development relative to other aquaculture industries. Even so, diseases and other biological challenges are still a key concern for the industry, and limit the industry's ability to grow. One of the most important disease challenges are those presented by viral diseases. A lack of aggregated estimates for economics losses associated with outbreaks of some viral diseases motivated the definition of the problem researched in this thesis: "How large are the aggregated economic losses associated with viral disease outbreaks in Norwegian salmonid aquaculture". The required data is at the time of writing only available for Norway.

The research problem was analyzed through a simulation model built on a partial budgeting framework. The model's framework was based on published literature within animal health economics, and similar exercises. Costs related to outbreaks was divided into biological losses, cost of prevention, -treatment, other extraordinary costs, and insurance payout. Actual reported biomass- and feeding data from all Norwegian salmonid farming sites was utilized in the model, in addition to both primary- and secondary sources for other model inputs. Based on available and obtained data, outbreaks between 2012 and 2016 of Pancreas disease (PD), Infectious Salmon Anemia (ISA) and Cardiomyopathy Syndrome (CMS) was included in the simulation model. The study had full coverage of outbreaks in Norway for 2014 and 2015.

The simulations show that PD caused direct costs for Norwegian farmers in 2015 of 2366 – 2775 NOKm, ISA 873 – 936 NOKm and CMS 647 – 848 NOKm. The simulation results show that the total aggregated direct costs associated with these viral disease outbreaks are an important source of economic losses in Norwegian salmonid aquaculture. The combined simulated losses from the three analyzed diseases are of a magnitude where they equate to four-fifths of previously published estimates on the direct costs associated with salmon sea lice in Norway. The results vary by year, but the study displays that particularly direct costs associated with PD are stable year-over-year.

The study further analyzes the implications of secondary infections with PD and CMS, and explores and discuss time- and geographic differences between outbreaks of each disease. Finally, the study analyze biological implications of outbreak using the production data.

The methodology applied in this thesis can be extended to cover more diseases and countries.

Oppsummering

Laksefiskoppdrettsindustrien har et unikt nivå med kommersialisering og teknologisk utvikling relativt til andre akvakulturindustrier. Sykdommer og andre biologiske utfordringer er allikevel fortsatt et stort problem for industrien, og begrenser effektivt industriens mulighet til å vokse. En av de viktigste biologiske utfordringene er virussykdommene. Mangel på et aggregert estimat på økonomiske tap relatert til utbrudd av enkelt virussykdommer motivert defineringen av problemstillingen for denne oppgaven: «Hvor stor er det aggregerte økonomiske tapene relatert til utbrudd av virussykdommer i norsk laksefiskoppdrett». De nødvendige datasettene for å gjennomføre analysen er i skrivende stund bare tilgjengelig for Norge.

Problemstillingen ble analysert gjennom en simuleringsmodell som ble bygd på et partial budgeting rammeverk. Modellens rammeverk ble basert på publisert litteratur og liknende øvelser. Kostnader relatert til utbrudd ble brutt ned i biologiske tap, prevensjonskostnader, behandlingskostnader, andre ekstraordinære kostnader, og forsikringsutbetaling. Rapporterte biomasse- og fôringsdata fra alle norske lakseoppdrettsanlegg ble anvendt i modellen, i tillegg til både primære- og sekundære kilder for andre modell parametere. Basert på tilgjengelig og anskaffet data, utbrudd av Pankreassykdom (PD), Infeksiøs lakseanemi (ILA) og Kardiomyopatisyndrom (CMS) ble inkludert i simuleringsmodellen.

Simuleringene viser at PD forårsaket direkte kostnader for norske lakseoppdrettere i 2015 mellom 2366 – 2775 NOKm, ILA 873 – 936 NOKm og CMS 647 – 848 NOKm. Simuleringsresultatene viser at totale aggregerte kostnader assosiert med utbrudd av virussykdommer er en sentral kilde til økonomiske tap i norsk laksefiskoppdrett. Kombinerte simulerte tap fra de tre analyserte sykdommer er av størrelsesorden hvor de tilsvarer fire-femtedeler av tidligere publiserte estimater på direkte kostnader ved lakselus i Norge. Resultatene er varierer mellom de analyserte årene, men studien viser at spesielt direkte kostnader knyttet til PD utbrudd er stabile år-over-år.

Studien analyserer videre implikasjonene av sekundære infeksjoner med PD og CMS, og utforsker og diskutere forskjeller mellom utbrudd basert på tid og geografi for hver av de analyserte sykdommene. Oppgaven analyserer til slutt biologiske implikasjoner av utbrudd ved å anvende produksjonsdata.

Metodikken som er anvendt i denne studien kan bli utvidet til å dekke flere sykdommer og land.

1. Introduction

1.1 Research question and problem

The global salmonid aquaculture industry is a 100 NOKb industry (FAO, 2017), with a high level of commercialization and technological development relative to other aquaculture industries. In all farming operations, maintaining animal welfare and biology is paramount. Diseases and other biological challenges are still a key concern for the salmonid aquaculture industry, and through regulations, limit the industry's ability to grow. One of the most important disease challenges are presented by viral diseases. Most of the published literature on economic implications of viral diseases concerns itself with the cost of an outbreak at a particular site, and not on an aggregated level. In the case of one such disease, Pancreas disease (PD), Pettersen (2016) describes that, "there have been few attempts to systematically quantify the impacts and estimate the costs from disease". Consequently, the salmonid farming industry does not have an aggregated estimate for the cost and the economics losses associated with outbreaks of some viral diseases. Understanding the aggregated implications of viral diseases should be important for both the industry and its stakeholders to prioritize mitigation efforts, and justify regulations aiming to eradicate the diseases. This motivated the definition of the research problem:

How large are the aggregated economic losses associated with viral disease outbreaks in Norwegian salmonid aquaculture

1.2 Scope of thesis

The main and overall focus of this thesis will be on Norwegian salmonid aquaculture. This definition is made due to the availability of data. The Norwegian aquaculture industry is a highly transparent industry, with a focus from the entire value chain, including government, on reporting practices and publicly accessible information. A key requirement of this thesis is to have access to production cycle- and outbreak history data. These datasets are at the time of writing only available at a satisfactory level for the Norwegian salmonid aquaculture industry. As will be explained further in section 5.3.2, the thesis will focus on the viral diseases Pancreas Disease (PD), Infectious Salmon Anemia (ISA) and Cardiomyopathy Syndrome (CMS) given data availability.

When analyzing the economic implications of outbreaks, the scope is on the national or regional industry as a whole, and not on individual companies. This is done with the intention of creating interesting and valuable conclusions for the industry and its stakeholders on an aggregated level, rather than highlighting the challenges faced by specific companies individually.

1.3 Methodology and outline of thesis

To research the defined problem, the thesis will first discuss the salmonid farming industry and its value chain to provide a context and a background for the thesis.

Chapter 3 discusses the biological challenges in Norwegian and global salmonid aquaculture. Each of the three main categories of biological challenges faced by salmonid farmers, bacterial-, parasitic- and viral diseases, are covered to provide the reader with insights of the relevant diseases, and how they relate to other important disease challenges. The chapter additionally presents a literature review of previously published studies assessing the economic implications of the different diseases and biological challenges.

The fourth chapter discusses the theoretical fundament for researching the defined problem, particularly the research area of animal health economics, including different methodologies for farm-level decision making and the impact of disease on farming operations. The section further discusses how the highlighted theory can be used to develop a model for researching the problem.

The fifth chapter presents the method and data utilized in the thesis. The study utilizes a partial budgeting framework for its simulation model. A partial budget is a method to assess the changes in profits of a certain change in production. The utilized partial budget consists of five components: biological losses, cost of treatment, cost of prevention, other extraordinary costs and insurance payout. The monetary biological losses are estimated as the difference between the economic profit of the production cycle experiencing a viral disease outbreak, and the economic profit of a control group consisting of comparable production cycles with an “attainable” level of health. Further, chapter 5 provides an overview of data and inputs utilized in the analytical model.

The sixth chapter presents the analysis and results. The results show that the implications of viral diseases is indeed severe, and in certain years can equate to four-fifths of estimated direct costs associated with salmon sea lice in Norway. The section concludes with a discussion of some of the specific characteristics of outbreaks that drive the economic implications of outbreaks, and analyze the biological implications of viral diseases against the control group.

Finally, the study concludes by presenting important findings and suggestions for extension of the utilized methodology.

1.4 Abbreviations

The following section provides a summary of the most important abbreviations in this thesis.

CMS	Cardiomyopathy syndrome
HSMI	Heart and skeletal muscle inflammation
HOG	Head-on-gutted / Gutted weight equivalent
EBIT	Earnings Before Interest and Tax
FCA	Free Carrier
FOB	Free-on-board
IPN	Infectious pancreatic necrosis
ISA	Infectious Salmon Anemia
Ktonnes	Kilo tonnes (1000 tonnes)
MAB	Maximum Allowed Biomass
NDF	Norwegian Directorate of Fisheries
NFSA	Norwegian Food Safety Authority
NOKm	Norwegian krone million
NOKb	Norwegian krone billion
NVI	Norwegian Veterinary Institute
PD	Pancreas disease
WFE	Whole fish equivalent

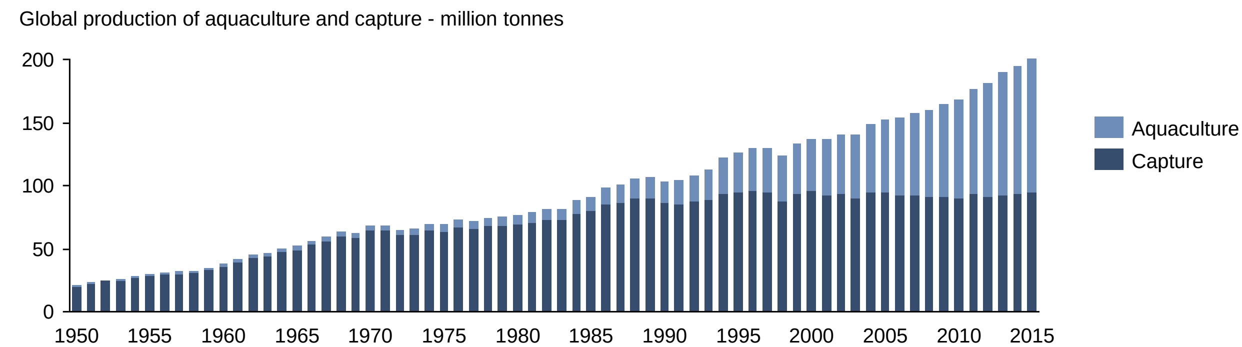
Appendix 1 provides an overview of Norwegian county geography and other geographical locations relevant for the thesis.

2. Industry and value chain description

The following section will present an overview of the salmonid aquaculture value chain. The chapter is designed to provide a background and context of the salmon farming industry, to better relate discussions and results presented later in the study. The chapter will first present the industry broadly, and give a short history of the salmonid farming industry in Norway. Secondly, the chapter will present the production cycle of salmonids. Further, section 2.2 presents key factors affecting the production process of salmonids. Section 2.3 and 2.4 presents an overview of supply and demand, and of the value chain. Lastly, section 2.5 highlights different cost categories in salmonid aquaculture, a discussion that will be directly relatable to components of the study's analytical model, presented later.

Capture fisheries has historically been the main source of fish volumes in the world, accounting for 90% of supply as late as in 1982. Aquaculture has experienced significant growth over the last thirty years, surpassing the output from capture fisheries for the first time in 2013 (FAO, 2017).

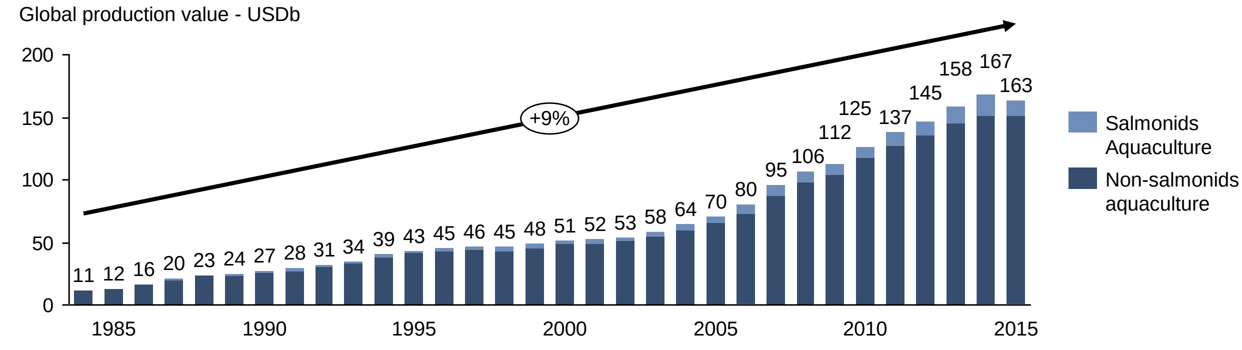
Figure 1: Development in capture fisheries and aquaculture volumes globally (1950-2015)



Source: (FAO, 2017)

Salmonid aquaculture is a global industry, harvesting 3.203 kilo-tonnes (ktonnes) whole-fish equivalent (WFE) of salmonids in 2016 (Kontali Analyse AS, 2017). In addition, approximately 1 million tonnes of wild salmonids are caught each year (Kontali Analyse AS, a, 2017). Even though the salmonid farming industry accounted for only 3.1% of global production volume from aquaculture in 2015, the value of the industry accounted for 7.8% of total value generation from aquaculture (FAO, Fish Stat, Kontali Salmon World 2016).

Figure 2: Global production value of salmonids and non-salmonids aquaculture (1984-2015)



Source: (FAO, 2017). *Note: Arrow displays the 1984-2015 CAGR.*

There are five species of salmonids that are currently farmed globally; Atlantic salmon, Small trout, Big trout, Coho and Chinook. Atlantic salmon is the most important species, accounting for 67% of supply. Salmonids are cold-blooded fish species, and therefore do not use energy to heat their bodies. This means that farming operations are effective (Marine Harvest, 2017). However, this also means that the species thrive in cooler water-temperatures, which places spatial limitations on possible production regions globally available for seawater-based farming operations.

Initial efforts of farming salmonids began in Norway in the 1960s. The first regulation of Norwegian aquaculture was introduced in 1973 (Aarset & Jakobsen, 2004). After a period of steady growth in the 1970s and early 1980s, the Norwegian salmonid aquaculture industry faced challenges towards the end of the 1980s, as growing global supply caused prices to fall (Aarset & Jakobsen, 2004). A need for regulation of the industry, led to the introduction of feed-quotas in 1996. From 2005, a Maximum Allowed Biomass (MAB) system replaced the feed quota system. In 2016, Norway harvested 1.255 ktonnes of farmed salmonids, of which Atlantic salmon accounted for 93% (Kontali Analyse AS, 2017). Today, salmonid aquaculture is the second largest industry in Norway, with a total production value of 68.3 NOKb in 2016 (Kontali Analyse AS, a, 2017), surpassed only by the oil and gas industry.

2.1 Production cycle of salmonids

Salmonids are anadromous fish, meaning that in in the wild egg spawns, hatches and has the first grower phase in freshwater, before the fish eventually migrates to seawater. The process of transformation the juveniles experience before migrating is called smoltification. After 1-4 years, depending on the species, wild salmonids will return to the river where they were born to spawn (Asche & Bjørndal, 2011). The production cycle of salmonids farming operations mimics that of wild salmonids. There are four steps of the biological process, broodstock and roe, production of fry, production of smolt and production of farmed fish. The following section will be based on Chapter 2 in Asche & Bjørndal (2011).

Broodstock and roe

To obtain roe for salmonid farming, eggs are stripped from broodstock and transported to a hatchery. Systematic breeding of salmon for broodstock started in Norway in 1972. The yolk-sack larvae are hatched after an incubation period of 2 months.

Production of fry

After the yolk-sack larvaes have hatched, they are referred to as fry. The fry feed on the contents of the yolk-sack for the first 2 months, before they start to digest feed. Asche & Bjørndal (2011) describe this period as a highly important one, and a faulted transformation process into using feeds have historically led to high mortality. Today, the survival rate in the hatcheries is typically over 70%. In the wild, salmonids spawn during the late spring and normally hatch in January. This means that the supply of farmed smolt have limited availability at certain times of the year (Guttormsen, 2008).

Production of smolt

When the fingerlings or fry have grown to a desirable size, the smoltification process takes place. The smoltification process is a physiological process where the fish are gradually adapted to seawater. To improve capacity utilization, farmers have gradually increased the size (weight) of the smolt before they are released into seawater. Given the natural limitation on availability of fry, smolts are mainly released into seawater twice a year. The spring generation, the S1 generation, is typically released in April and May, and the autumn generation, the S0 generation, is typically released in August, September and October (Sjømat Norge, n.d.).

Production of farmed fish

After the fish has completed the smoltification process, the smolts are transferred to the grow-out sites by wellboats. The grow-out phase in seawater takes place in sea pen. Improvements of pens, increased pen sizes and automated feeding systems have enabled the scale of each site to increase. A standard site has seen its output increase from 100 to over 5000 tonnes of fish per year from the late 1980s to today. The fish typically spend between 14-24 months in the seawater grow-out stage (Marine Harvest, 2017). When the production cycle of a given site has been completed, the site is fallowed.

The length of the production process in seawater has an upper limit, as the fish will start to mature. A salmon does not die during this process, but the quality degradation during this period is significant. It can take up to a year for a mature salmon to regain optimal quality.

The viral diseases considered in this study predominately affect salmon during seawater grow-out stage of the production cycle.

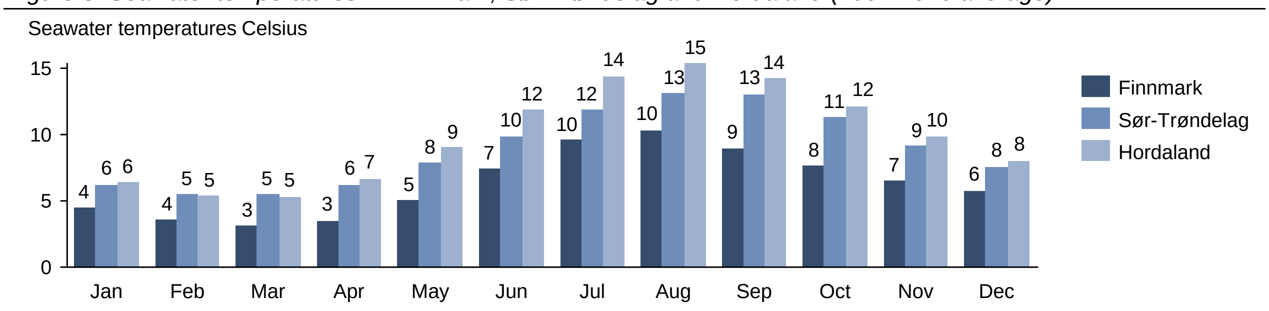
2.2 Factors influencing the production process of salmonids

Several factors influence the production process of salmonids. These factors are discussed at various instances throughout the thesis. The following section introduces some of the most important ones.

Fish growth

Several factors affect fish growth, both abiotic and biotic. Abiotic factors relates to non-living parts of the environment that affects the creatures and workings of ecosystems. Time, temperature and light are the most important abiotic factors (Aunsmo, et al., 2014). Salmonids are cold-blooded, and thus the temperature plays an important role for its growth rate (Marine Harvest, 2017). The optimal temperature range for growth in salmonids is 8 to 14 degrees Celsius. Higher seawater temperatures can increase disease risk. In Norway, there are variations between the different counties' seawater temperatures, and thus the growth of fish varies between different counties.

Figure 3: Seawater temperatures in Finnmark, Sør-Trøndelag and Hordaland (2004-2016 average)

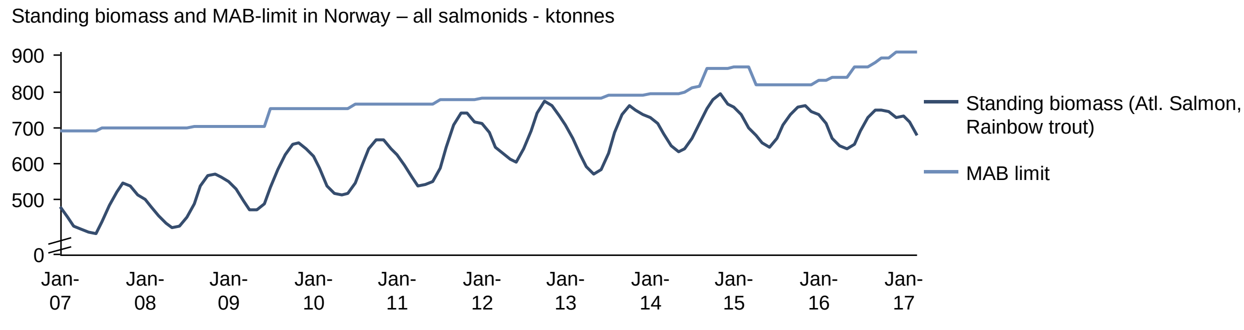


Source: (Lusedata, u.d.)

Biomass

The stock unit tonnage of fish is referred to as standing biomass. Most production countries of salmonids around the world have adapted production-controlling regimes that limit either the standing biomass or the density of a farming site (Marine Harvest, 2017). In 2005, Norway introduced the MAB-regime that places a limit on the standing amount of biomass at each site and each license. In Norway, it is required to both have a farming license and an approved location (site) to farm salmonids (Lovdata, 2008). In general, licenses south of Troms have 780 tonnes of MAB, while licenses in Troms and Finnmark have 945 tonnes. A typical farming site has a MAB between 2.340 and 4.680 tonnes.

Figure 4: Standing biomass and Maximum Allowed Biomass (MAB) limit for all salmonids, Norway

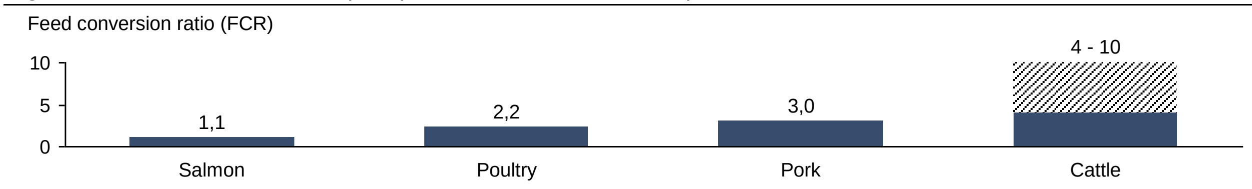


Source: (Kontali Analyse AS, a, 2017; Marine Harvest, 2017)

Feed

Effectiveness in farming operations is typically determined by the respective feed conversion ratio (FCR) of the farm (Dijkhuizen & Morris, 1997). The FCR measures how many units of feed are required to increase the animal's bodyweight by one unit (Marine Harvest, 2017). Salmonids are one of the most effective farm animals in the world. Compared to other important proteins sources such as poultry, pork and cattle, salmonids have a significantly better FCR.

Figure 5: Feed conversion ratio (FCR) of different domesticated protein sources



Source: (Marine Harvest, 2017)

There are many different types of feed available for salmonid aquaculture farmers, each with different feed formulation, pellet size and cost. A typical feed company will offer a range of starter feeds, transfer feeds, grow-out feeds and health feeds (BioMar, n.d.).

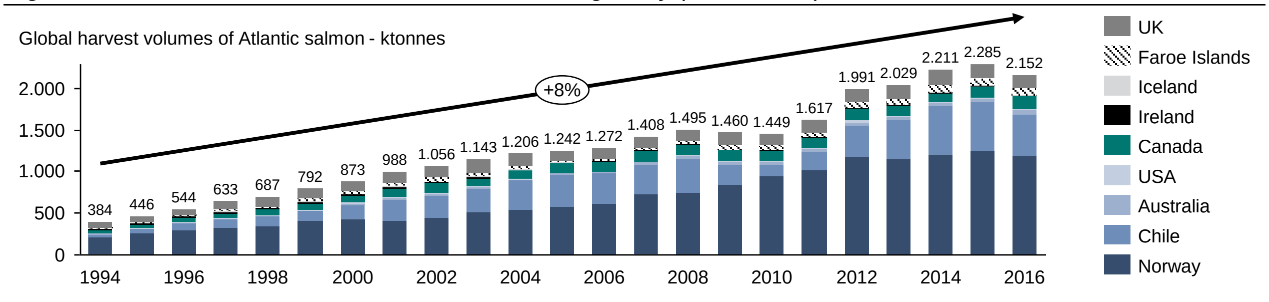
2.3 Salmonid aquaculture supply and demand

The following section discusses supply and demand of salmonids. The section provides an overview of Norway's position as a salmon supplier, and discusses demand and consumption patterns for salmonids. Based on limitations related to data and information regarding demand and supply of all salmonid species, Atlantic salmon is the only species that will be analyzed in the following section. Atlantic salmon is the most important salmonid species in both Norway and globally. After this section, the word salmon will be used to describe all species of salmonids.

Supply of Atlantic salmon

Norway and Chile are the two most important countries for supply of Atlantic salmon, accounting for 78% of global harvest in 2016 (Kontali Analyse AS, 2017). Other key producers globally include the United Kingdom, Faroe Islands, Canada and Australia. Analyzing the economic implication of viral disease outbreaks from a Norwegian perspective is thus a suitable scope of focus. The supply of salmonids have increased with a CAGR of 8% from 1994 to 2016.

Figure 6: Historical harvest volumes of Atlantic salmon globally (1994 - 2016)



Source: (Kontali Analyse AS, a, 2017)

Demand for Atlantic salmon

The EU market is the largest market for Atlantic salmon globally, consuming more than 1 million tonnes in 2016 (Kontali Analyse AS, a, 2017). The US market is the largest single country market for Atlantic salmon, consuming 413 ktonnes in 2016. Thus, these two markets consumed more than 65% of global harvest volumes of non-small trout salmonid harvest in 2016 (Kontali Analyse AS, 2017).

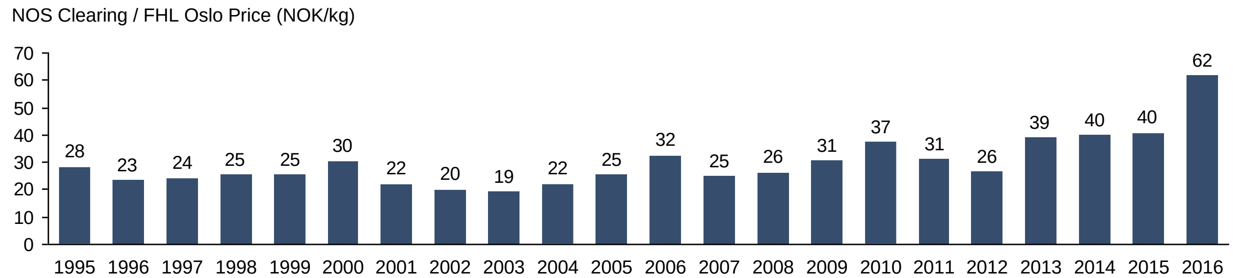
Due to lower supply growth in recent years, salmon prices have increased significantly. This has consequently increased the value of Atlantic salmon consumption globally from 3.15 EURb in 2004 to 12.35 EURb in 2016 (Kontali Analyse AS, a, 2017; Marine Harvest, 2017).

Price development of Atlantic salmon

There are several quoted reference prices for salmon in the world. In Europe, the FCA Oslo price, published by Nasdaq, is the reference price used by most parties. In the Americas, prices for fillets in Miami, and for whole fish in the Northwest and Northeast are the usual quotes.

Salmon prices are volatile, with little evidence of significant market power. There are several factors that help explain the volatility of salmon prices, including: supply changes, demand changes, hedging instruments and general food price trends (Øglend, 2013).

Figure 7: Historical NOS Clearing / FHL Oslo Price[1] (annual nominal average 1995-2016)



Source: (Sjømat Norge, u.d.; Nasdaq, u.d.)

Changes in supply can be explain many of the larger price movements in recent years. In particular, prices spiked when the supply from Chile fell during its Infectious Salmon Anemia (ISA) crisis in 2009-10, and again in 2016 following the Chilean algae bloom (Reuters, 2016).

Salmon prices are normally quoted for different weight-classes, each of which tend to have a different price point throughout the year. The spread between the different weight-classes typically vary throughout the year, but is generally the highest during the summer months when farmers are moving from harvesting their two-year S0 generation, to harvesting their 1-year S1 generation, as the supply of large fish is declining in this period (Marine Harvest, 2017).

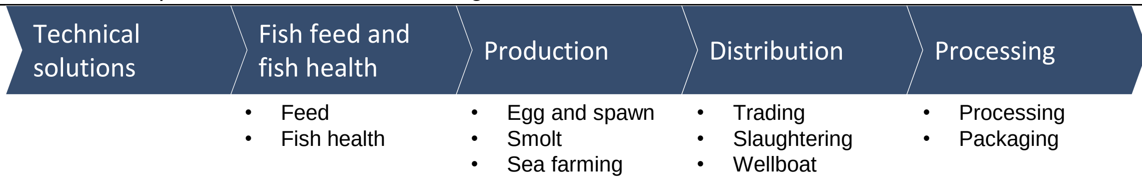
2.4 Salmon aquaculture value chain

Several different value chain segments have direct connection to viral disease outbreaks. The following section introduces different segments of the value chain, to provide a background for discussions later in the study. The value chain for salmon aquaculture can be divided into five main categories: suppliers of technical solutions, fish feed and –health, production, distribution and processing present in the value chain (Moe, 2016). Although companies traditionally have been limited in their scope and participation in different industry segments, high profitability and a strategy of consolidation has led many farming companies, in particular, to integrate increasing number of sub segments. Analyzing and understanding the different value chain segments is relevant for further discussions in the thesis, including the specific role of each segment with

[1] Referring to a price quote previously published by the Norwegian Seafood Federation and NOS Clearing.

regards to viral diseases. The following overview will highlight some of the most important sub segments of the value chain.

Figure 8: Salmon aquaculture value chain sub-segments



Source: (Moe, 2016, author creation)

Upstream industry

The upstream industry comprise of all segments of the value chain that develop raw material, i.e., adds costs, up until completion of the product. Within this study, the upstream industry refers to the activities in the value chain until harvest of the salmon.

Broodstock and ova

There are between 5-7 producers of ova in Norway, producing eggs with a combined value of 600 NOKm (Kontali Analyse AS, 2017). Some of the major salmon farming groups in Norway have in-house production of ova and broodstock.

Vaccines

Primarily two companies supply vaccines to the salmon farming industry, Pharmaq and MSD Animal Health (MSD). Pharmaq and MSD generated approximately 1.1 NOKb within the aquaculture vaccine market in Norway in 2016 (Company accounts, n.d.; Furuset, 2017).

Feed production

The global salmon feed market has for the last 10 years been dominated by three major producers; Skretting, BioMar and EWOS. In mid-2014, Marine Harvest began production of feed from its own feed plant in Norway, and currently has obtained a 20 % market share in Norway (Kontali Analyse AS, a, 2017). The other three major feed producers globally are present in all of the major aquaculture regions around the world (Skretting, u.d.; Cargill, u.d.; BioMar, u.d.).

Profitability in the feed production segment is low, but with small variations even though the price of input factors (raw materials) can vary significantly. This is because the feed contracts in the salmon farming industry have a cost-plus clause, i.e., that farmers carry the exposure and risk associated with raw material price fluctuations (Marine Harvest, 2017; Richardson, 1918). Therefore, the efficiency of the feed mill is therefore the main driver of feed production margins. Lower demand for feed during the winter months in the Northern Hemisphere, combined with feeds' expiry dates, means that the production and thus the utilization of the feed mills is lower in the winter. Consequently, feed producer margins are typically lower in H1 than in H2 (Schouws & Co, u.d.; EWOS, u.d.; Marine Harvest, 2017).

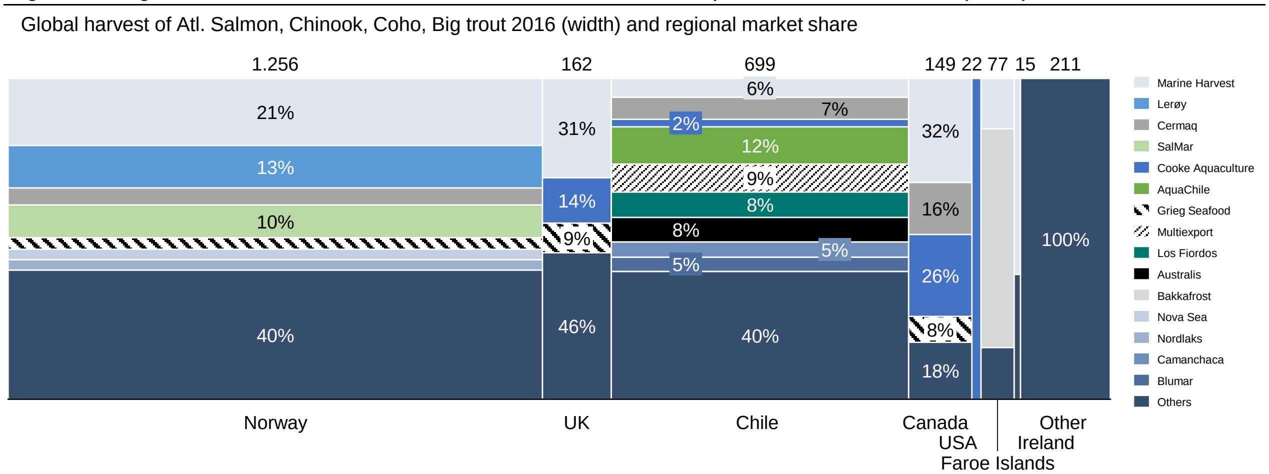
Wellboats

In Norway, the wellboat market is controlled by three major companies; Sølvtrans, Rostein and Norsk Fisketransport. These companies accounted for 73% of the total well-boat capacity charted in Norway at year-end 2016 (Haukvik, 2017). The wellboat market is highly profitable, and has historically had the highest average margin of the upstream value chain segments.

Farmers

Large national and multinational players dominate the farming segment. Consolidation activities, buyouts and mergers have meant that the number of companies controlling the majority of production has fallen over the last two decades. Particularly companies such as Marine Harvest, Lerøy, SalMar and Cooke Aquaculture have completed several mergers and takeovers to consolidate the industry (Marine Harvest, 2017). The ten largest producers of salmon controlled 49% of global non-small trout harvest volumes in 2016 (Kontali Analyse AS, 2017).

Figure 9: Regional harvest volumes of non-small trout salmon and producer market share (2016)



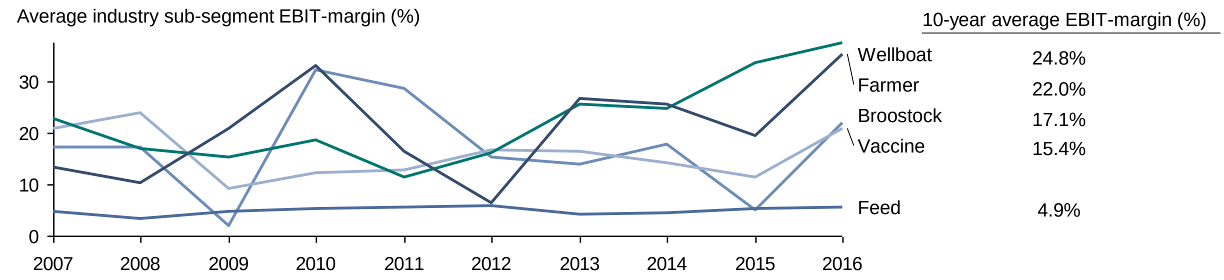
Source: (Kontali Analyse AS, 2017, author creation)

Farming has historically been the most profitable upstream segment (in terms of absolute value creation). However, regional biological challenges, algae blooms, and differences in management practices have meant that there historically have been differences in profitability between the different farming regions (Asche & Bjørndal, 2011).

Upstream value chain profitability

The profitability of the upstream value chain varies between the segments. Companies within each segment were identified to evaluate the profitability of each segment, displayed in figure 10.

Figure 10: Average industry sub-segment EBIT-margin (%) in Norway (2007 - 2016)



Sample companies: Wellboat: Sølvtrans Rederi, Norsk Fisketransport, Rostein, Bømlo Brønnbåtservice, Nordlaks Transport, Seigrunn, Mowi Star, Seivåg Shipping, Napier, Folla Sjøtransport, Polarfjell, Frøy Sjøtransport. Farmer: Norwegian Directorate of Fisheries (2007 – 2016). Broodstock/Ova: AquaGen, SalmoBreed, Rauma Stamfisk, Nord Norsk Stamfisk. Feed producer: Nutreco Fish Feed, EWOS, BioMar, Marine Harvest Feed. Vaccine: Pharmaq

Source: (Company accounts, u.d.; author creation).

Downstream industry

The downstream industry includes companies and organizations that sell and distributes salmon products. The participation in the value chain among the salmon farmers generally extend to processing, and sales and marketing operations and the downstream industry is therefore defined to only include these segments.

Processing

There are two types of fish processing: primary- and secondary processing (Marine Harvest, 2017). Primary processing consists of slaughtering and gutting operations. Secondary processing is further development of slaughtered fish for consumption, such as filleting or smoking. Secondary processing is often referred to as Value-Added processing (VAP). European processing is typically carried out in Central Europe, in countries such as Poland and France.

Sales and marketing operations

Most of the integrated salmon farming companies have their own sales and marketing operations. These companies generally are organized as a joint processing- and export operation. However, there are also several independently organized sales (exporter) companies. Salmon exporters are trading salmon in a highly competitive market, and the margins are consequently low.

2.5 Salmon aquaculture cost structure

This study utilizes cost inputs to simulate the economic result of all started, and completed, production cycles in Norway between 2012 and 2016, as presented further in Chapter 5. Analysis of the industry's cost structure is therefore important to provide a background of key concepts applied later in the study. Section 5.3 provides a discussion of the inputs for production cost used in simulations and modeling to research the defined problem in the thesis. Iversen et. al. (2015) grouped production cost in salmon farming into eight different categories: smolt-, feed-, labor-, insurance-, other operating-, harvest- and wellboat costs, and yield loss. The following section will present key considerations when analyzing the production cost of salmon aquaculture.

Smolt

The cost of smolt is dependent on different factors related to its production process. Particularly the size of the smolt has important implications for the costs (Iversen, et al., 2015). The larger the smolt is before it is being transported to seawater will, for instance, affect the accumulated feed cost, and also costs associated with powering water recycling units (Iversen, et al., 2013).

Feed cost

The cost associated with feeding is a function of the price of the feeds used, and the respective feed conversion ratio throughout each step of the production cycle (i.e., consumption of each type of feed) (Marine Harvest, 2017). The three seawater feed types that will be analyzed in this thesis include normal grow-out feed, sea lice treatment feed and functional PD-feed. In reality, feed producers produce several hundred versions of both functional- and grow-out feeds, each with different nutritional content and purpose. The total cost associated with feed is consequently dependent on the quantity of feed fed, and the feed price.

Labor cost

The labor cost in aquaculture has undergone significant changes since the early days of salmon farming. With technological development and more automation, the need for workers to perform normal tasks has been reduced significantly (Asche & Bjørndal, 2011). The use of labor in Norwegian salmon aquaculture has not increased much since the late 1980s, even though the output has increased significantly (Henriksen, et al., 2014). Due to an increase in labor-intensive activities at the farming sites, the internal- and/or outsourced labor cost have been reported to increase somewhat in recent years (Iversen, et al., 2015).

Insurance cost

Several different types of insurances are available to aquaculture farmers, including policies that cover, among other factors, biomass, algae blooms, environmental pollution and damages (IF, u.d.). Insurance companies insuring aquaculture in Norway describes that their biomass insurance typically covers three areas of potential losses; mortalities, escapes and theft, and they offered four different tiers of mortality insurance, each with different degree of coverage (Insurance company pers. com., 2017; Insurance company pers. com., 2017). The cost of insurance is small relative to other production costs, but the insurance payout can be important for the overall implications of disease outbreaks. The insurance premiums on biomass are calculated monthly, based on the reported biomass volume, weight mix and a predefined value rate for different weight classes (Insurance company pers. com., 2017). Consequently, insurance premiums can be regarded as a variable cost.

Other operating costs

Several cost categories are included within other operating costs. Three different categories of other operating costs generally exist: maintenance, machinery and health costs (Iversen, et al., 2015). In recent years, health related costs particularly related to sea lice treatments have become the most prominent cost component in this category.

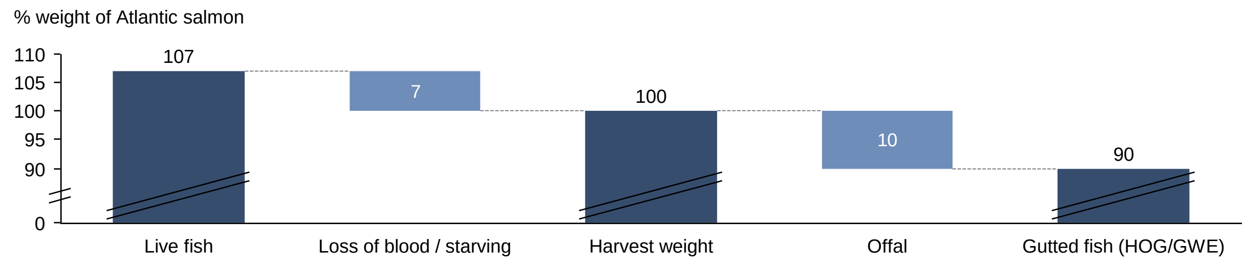
Harvesting and wellboat transportation

When the fish is ready for harvest, a wellboat transports the fish to a slaughtering facility. A wellboat is a purpose built vessel for transportation and processing of live fish (Strand & Stovner, 2016). The cost of these vessels is dependent on wellboat time charter rates. Most of the large and medium sized salmon farming companies have their own gutting/slaughtering facilities. Therefore, the costs associated with harvesting and slaughtering is for some companies dependent on the capacity utilization of their slaughtering facilities (Iversen, et al., 2015). Even so, some farming companies can, and will, hire external capacity for harvesting and slaughtering operations, were they have less control of the utilization.

Yield loss

A salmon has to be slaughtered before it reaches the market. Before harvesting, the fish goes through a starvation period. During the initial step in the slaughtering process, the fish's blood is removed, upon which the fish weight is referred to as whole-fish equivalent (WFE) (Kontali Analyse AS, a, 2017). During the slaughtering, also fish offal is removed. When these operations have been completed, the remaining fish weight is referred to as head-on-gutted (HOG), which is about 90% of the WFE weight.

Figure 11: Weight conversion rates for Atlantic salmon



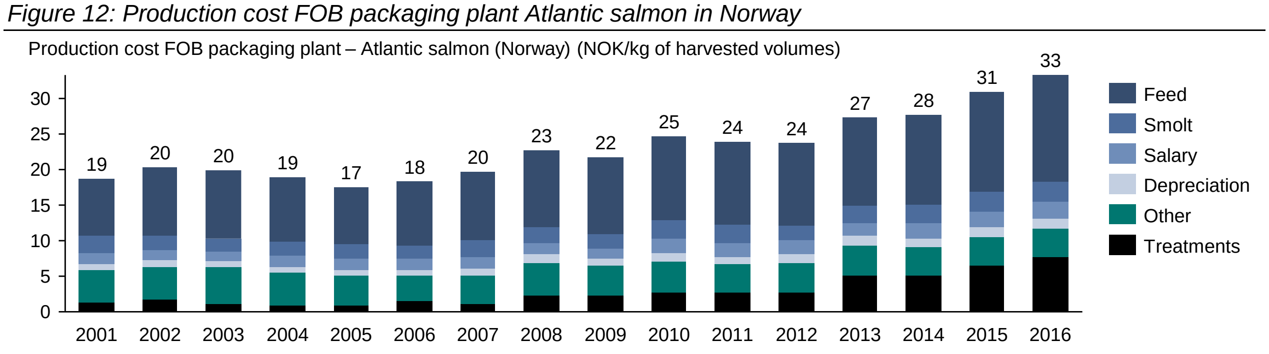
Source: Kontali Analyse AS, (a, 2017)

As the farmers incur costs not only to grow the fish meat, but also the blood, organs and other offal, the farmers experience a yield loss when the fish is slaughtered. This yield loss can be quantified by analyzing the released stocking costs at the time of harvesting.

Financial cost

The interest and financial cost of each company is highly dependent on company specific factors such as the probability of default and the creditors' exposure/loss in the event of a default (Johnsen, 2016). Most Norwegian farmers currently operate with limited financial risk, and financial costs are typically small. The development in risk-free interest rates in the last decade has offset an increase in investments that farming companies has endured during the same time period, resulting in stable financial costs (Iversen, et al., 2015).

Figure 12: Production cost FOB packaging plant Atlantic salmon in Norway



Source: Iversen, et al., (2015); Kontali Analyse AS, (b, 2017); Norwegian Directorate of Fisheries, (2016)

3. Biological challenges in salmon aquaculture

As farming salmon is a biological process, biological problems are a key concern for farmers. There are currently three categories of disease challenges that face salmon farmers globally: bacterial-, parasitic- and viral diseases (Hjeltnes, et al., 2017). Disease prevention and control authority is in Norway held by the Norwegian Food Safety Authority (NSFA) (Lovdata, 2008). Dependent on the disease, the NFSA can, for example, mandate prescheduled slaughter, establish control- and monitoring areas, issue fines and change MAB-allowances. Diseases associated with salmon farming can either be listed or not listed. Whether a disease is listed is defined based on six criteria (Norwegian Food Safety Authority, u.d.; Aukner & Haatuft, 2015):

1. The disease is not listed in the fish health directive
2. The disease may represent a significant risk to the animal health situation in aquaculture
3. It is difficult to combat the disease and keep it under control at farming sites
4. Disease-free areas can be achieved and sustained, where it is important to control the disease
5. The disease is clearly defined on the basis of infectious agents and / or pathological findings
6. The disease may be a threat to wild stocks of aquatic animals if not combated

A listed disease is subject to certain regulations set out by the authorities, where the ultimate aim is to limit or eradicate the listed disease. There are currently three different lists of diseases, each with a separate set of measures available to the NFSA in the event of an outbreak. In addition, a disease can be unlisted and therefore not have a specific, coordinated mitigation effort. As displayed in the Figure 13, two of the diseases analyzed in this thesis are listed, PD and ISA.

Figure 13: Overview of listed fish diseases in Norway

List 1 - Exotic diseases	List 2 – Non-exotic diseases	List 3 – National diseases
Epizootic haematopoietic necrosis	Viral haemorrhagic septicaemia (VHS)	Bacterial kidney disease (BKD)
	Infectious hematopoietic necrosis (IHN)	Infection with nodavirus
	Infectious Salmon Anemia (ISA)	Furunculosis ssp.
		Pancreas disease (PD)
		Systemtic infection with flavobacterium
		Salmon sea lice

Source: Norwegian Food Safety Authority (u.d).; Aukner & Haatuft, (2015)

The following chapter will present some of the key biological challenges in Norwegian salmon aquaculture, by each of the three categories. The section both discusses the diseases and presents a literature review of previously published literature on the economic implications of each disease. Although the thesis focuses on viral diseases, understanding and relating these diseases to other biological challenges in salmonid farming is important for assessing the context and severity of the challenges faced.

3.1 Bacterial diseases

Bacterial diseases was in the early stages of salmon farming in Norway the greatest challenge. During the 1980s, the salmon farmers in Norway responded to several disease problems by increasing the usage of antibiotics (Asche & Bjørndal, 2011). Outbreaks of bacterial diseases came under control with the introduction of oil-based vaccines in 1992. This quickly made antibiotics redundant, lowering the usage. Currently, the bacterial disease situation in Norwegian salmon farming is “fairly good” (Hjeltnes, et al., 2017), and similar situations have been described in Scotland and Canada (Marine Harvest, 2017).

The lower prevalence of bacterial disease in Norwegian salmon farming also means that the economic losses associated with bacterial diseases are lower. Winter ulcer is currently believed to the most severe disease, costing the industry close to 100 NOKm per year, primarily from downgrading at the slaughtering facility (Jensen, 2015).

3.2 Parasitic challenges

Parasites, most prominently salmon sea lice, represent the most significant biological challenge in Norwegian and global salmon aquaculture (Hjeltnes, et al., 2017). In Norway, in particular, it also represents the limiting factor for future growth (The Norwegian Government, a, 2017).

3.2.1 Salmon sea lice

There are two types of sea lice that are a concern to the salmon farming industry globally, *Lepeophtheirus salmonis*, which affects the Northern Hemisphere, and *Caligus rogercresseyi*, which affects farms in Chile. Sea lice are a naturally occurring crustacean (Hjeltnes, et al., 2017).

Adult female lice can each produce several hundred eggs (Hjeltnes, et al., 2017). It is therefore the number of female sea lice that is of concern, as these have the potential to reproduce quickly. The maximum permitted lice burden in Norway is defined by regulation, where the average count of female sea lice per fish is the limit. All farmers have since 2012 been mandated by law to weekly count and report the average number of sea lice, given that seawater temperatures are above 4 degrees Celsius (Hjeltnes, et al., 2017). If a farmer exceeds a defined limit of 0.5 average female sea lice per fish, the NFSA can impose multiple measures, including forced harvest and reduced biomass allowances.

There are no vaccine against sea lice (Jensen, 2017). In order to comply with the sea lice count limit, the farmers typically have to perform multiple treatments during the production process. There are three main types of sea lice treatments currently available: feed, medical and mechanical. Mechanical treatments became widely popular in 2016 (BarentsWatch, n.d.), mainly driven by problems with resistance towards medical agents such as hydrogen peroxide.

As a fourth alternative, the farmers may also use biological treatment, cleaner fish, to mitigate the challenges of sea lice. Cleaner fish are different species of wrasse that will eat sea lice on salmon living in the cages. The wrasse can either be caught from commercial fisheries, or they can be farmed. The usage of cleaner fish has become popular in recent years, with about 60% of farms using them in 2017 (Lusedata, n.d.).

Previous literature on the economic implications of sea lice

As described in the section above, the stricter regulation on sea lice counts has increased the number of treatments, cleaning operations and mortality. Abolfilia et. al. (2017) found that lice parasitism produced 436 USDm (2444 NOKm[2]) in damages to the Norwegian salmon farming industry in 2011. Iversen et. al. (2015) concluded that the increase in sea lice related production cost was driven by several mitigation and control measures. The total sea lice mitigation cost in Norway was estimated to be three NOKb in 2014, and close to five NOKb in 2015 (Iversen, et al., 2015; Jensen, 2016). The estimates from Iversen et. al. (2015) focused on the direct costs associated with sea lice mitigation. However, this excludes the productivity loss associated with lower growth post treatment. Before and after treatments, the fish has to be starved for an extensive period, postponing growth. EWOS has estimated that, with a salmon price at 55 NOK/kg, the total foregone revenue associated with the lower growth amounts to 5.9 NOKb, bringing the total sea lice cost above 10 NOKb per year (Bruarøy, 2015).

3.2.2 Amoebic Gill Disease (AGD)

AGD is caused by the amoeba *Paramoeba perurans.* The pathological changes for fish that are affected by outbreaks are limited to the gills. The disease has in recent years caused losses to the Scottish and Irish salmon farming industries (Hjeltnes, et al., 2017). In 2013, AGD mortality in

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[22] USD/NOK exchange rate 5.6074 - Norges Bank FY 2011 average (Norges Bank, 2017).

Scotland cost farmers more than 30 GBPm (Vass, 2013). The treatment of AGD is generally limited to hydrogen peroxide and freshwater (Hjeltnes, et al., 2017).

Previous literature on the economic implications of AGD

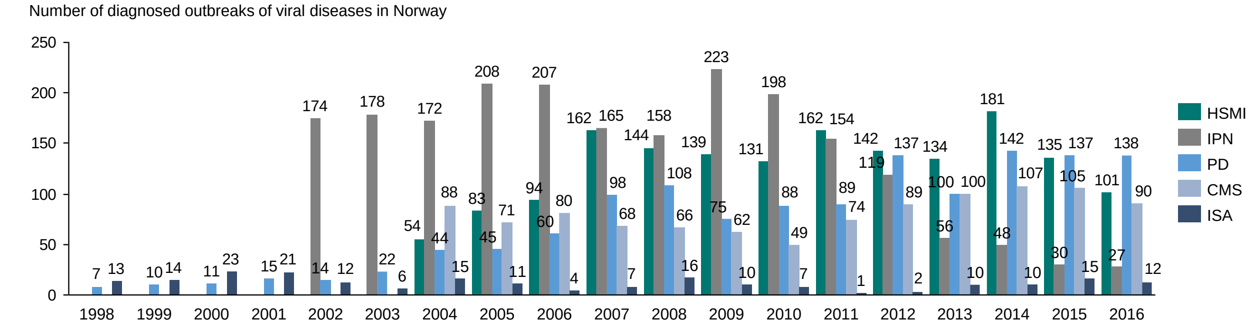
No dedicated study of the economic losses associated with AGD has been identified. However, treatment is a key control measure, and thus mitigation and treatment costs are prominent. Marine Harvest reported up until Q4-2014 their AGD mitigation and treatment costs in Norway (Marine Harvest, n.d.). Based on the company's 2014 harvest volumes, AGD mitigation cost Marine Harvest 154 NOKm in 2014 in Norway. Given Marine Harvest's share of harvest in 2014, and assuming the other companies in Norway had similar costs associated with AGD mitigation, the total national costs could be as high as 680 NOKm per year.

3.3 Viral diseases

The third and final group of biological challenges that currently affect Norwegian salmon aquaculture is the viral diseases. The viral diseases are besides sea lice, the biological challenge that currently have the greatest effect on fish health (Hjeltnes, et al., 2017). There are several differences between viral-, bacterial- and parasitic diseases. Bacteria are generally intercellular organisms, while viruses are intracellular, meaning they live inside the host cell and alter the host cell to produce virus rather than genetic material (Aukner & Haatuft, 2015). Further, not all bacteria are pathogenic, implying they cause harm for the host, but all viruses are pathogenic. There are several difficulties associated with developing virus vaccines given current technology, that mean that viral disease vaccines are less effective than bacterial vaccines (Vaccine producer pers. com., 2017). Parasites are more advanced organisms than viral- and bacterial organisms, and will also exploit the host so that damage is inflicted (Aukner & Haatuft, 2015).

The following section will introduce the five most important viral diseases currently present in Norway. The development in outbreaks will be discussed for each disease, respectively, in the succeeding section.

Figure 14: Annual number of diagnosed HSMI, IPN, PD, CMS and ISA outbreaks in Norway (1998 - 2016)



Source: (Hjeltnes, et al., 2017; Hjeltnes, et al., 2016). *Note: Difference in start year for data due to availability of data.*

3.3.1 Cardiomyopathy Syndrome (CMS)

CMS is caused by the virus *Piscint myocarditt.* The disease is traditionally diagnosed during the second year of the seawater stage, and the economic impact of the disease can therefore be significant (Hjeltnes, et al., 2017). The economic losses of the disease is typically confined to mortality. Brun et. al. (2003) estimated that the average increase in mortality associated with CMS was 3.6%, but mortality have been described to vary from "negligible to almost 100%" (Timmerhaus, 2011; Brun, et al., 2003). CMS is not a listed disease in Norway.

There is no known treatment or vaccine against CMS. It has been proven that handling operations such as de-lousing and transportation may trigger outbreaks (Hjeltnes, et al., 2017), and fish that has been diagnosed with CMS should therefore be handled as little as possible.

Previous literature on the economic implications of CMS

Brun et. al. (2003) estimated that CMS cost the Norwegian salmon farming industry between 33.5 NOKm to 66.3 NOKm per year, based on production, cost and price data from 1999 and 2000. As described in the preceding section, CMS is a disease that typically develops into a clinical disease during the second year of seawater production. This means that with higher salmon prices, the losses become significantly more prominent.

3.3.2 Heart and Skeletal Muscle Inflammation (HSMI)

HSMI is caused by the virus *Piscine reovirus (PRV)*, but fish with PRV virus might not necessarily develop HSMI. The disease is traditionally diagnosed during the first year of the seawater stage. HSMI can result in vary variable mortality levels, with losses commonly reported following management and handling procedures (Hjeltnes, et al., 2017). From June 2014, HSMI has not been a listed disease in Norway, and thus do not have a coordinate eradication effort.

There is no known treatment or vaccine against HSMI. Avoiding operational measures that can stress the fish is an important strategy to prevent mortality of weak fish (Hjeltnes, et al., 2017).

Previous literature on the economic implications of HSMI

Studies have documented the relationship between the PRV virus and the development of melanin focal changes in Atlantic salmon (Koppgang et. al 2015). In Norway, these focal changes have increased from affecting 13% of harvested fish in 2011 to 19% in 2015, meaning that currently one in five Norwegian Atlantic salmon have one or more dark patches at harvest (Hjeltnes, et al., 2016). Walde and Alarcòn (2016) reported that in 2010, the problem had been estimated to cost approximately 500 NOKm (Hjeltnes, et al., 2016). HSMI is associated with PRV, and is therefore believed to be a key reason for the development of melanin patches in the white skeletal muscle. Koppang et. al. (2015) estimated that these melanin focal changes currently could cost the industry up to one NOKb per year.

3.3.3 Infectious Pancreatic Necrosis (IPN)

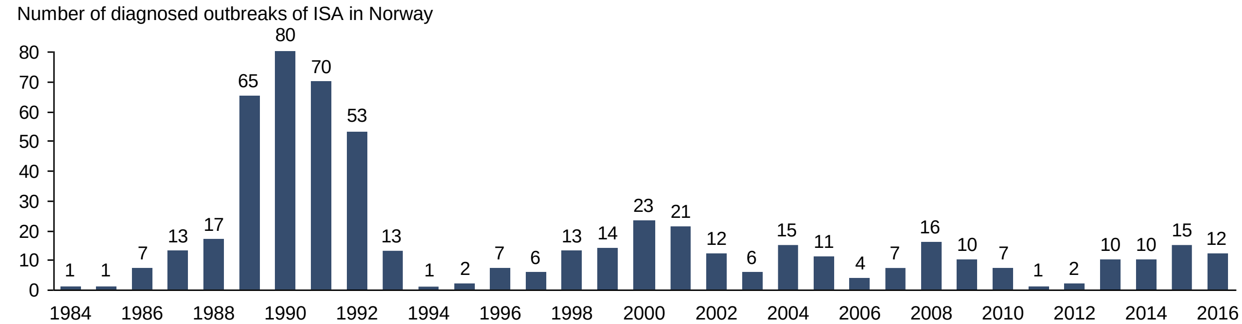
IPN is a virus which belongs to the genus *Aquabirnaviridae.* IPN is traditionally a viral disease that affects salmon during the freshwater stage, but can also cause outbreaks shortly after smoltification (Hjeltnes, et al., 2017). The outbreak mortality is often higher in the freshwater stage, but the economic losses of outbreaks are naturally higher during the seawater phase (Norwegian Veterinary Institute, b, 2015). IPN is not a listed disease in Norway.

After 2008, the number of IPN outbreaks have been reduced significantly. The NVI attributes this mainly to increased usage of QTL-based stocks, together with efforts to eradicate “house” strains (Bornø & Linaker, 2015). Additionally, most smolts are now also vaccinated against the disease.

3.3.4 Infectious Salmon Anemia (ISA)

ISA is caused by an *orthomyxovirus* (Hjeltnes, et al., 2017). The disease share several characteristics with the influenza virus (Aukner & Haatuft, 2015). The first diagnosed outbreak of ISA in Norway was in 1984. Since then, the disease has spread to Atlantic Canada, Scotland, the Faroe Islands, Maine, and eventually to Chile (Scheel, et al., 2007). In Norway, the number of outbreaks increased rapidly from 1984 to the peak in 1990, before eventually normalizing over the last two decades (Hjeltnes, et al., 2017). The reduction in the number of outbreaks has been attributed to introduction and implementation of different preventive measures (Scheel, et al., 2007). ISA has been diagnosed along the entire Norwegian coast, however, with a higher incident rate in the northern- and central parts of the country. There are currently ISA-vaccines on the market, but special marketing regulations apply for its usage.

Figure 15: Annual number of diagnosed ISA outbreaks in Norway (1984 - 2016)



Source: (Hjeltnes, et al., 2017; Hjeltnes, et al., 2016).

ISA regulation in Norway

ISA became a notifiable disease in Norway in 1988, after it had been shown that the disease was contagious (Thorud & Håstein, 2002). During the 1990s, multiple studies documented the spread of ISA, for instance from purchase of infected smolts, release of untreated water into the sea from slaughtering plants, and the distance between farms. In 1996, the government introduced guidelines on the mitigation of ISA (Thorud & Håstein, 2002). The guidelines introduced both combat- and monitoring zones around an infected farm, a practice that is still in place today. Within the combat zone, all sites with proven or suspected outbreaks of ISA shall slaughter or destruct the fish within a certain deadline imposed by the NFSA (Lovdata, 2017). Additionally, there are regulations on mortality reporting practices, smolt release, fish transportation, and fallowing within the combat zone. Within the monitoring zone, the farmers have to, for instance, report mortality on a daily basis, and there are similarly regulations on fish transportation.

There are two different types of fish material streams that can emerge when a farming site is diagnosed with ISA. Category 2 includes fish that has died on its own and clinically sick fish (Norwegian Food Safety Authority, 2016). No sales- or salvage value is available for category-2 volumes. The second category, category 3, the remaining fish individuals, can be used for both human consumption and as feed ingredients for food producing animals. When an ISA outbreak is diagnosed and the NFSA mandates the removal of the fish on a site, the NFSA does not “interfere whether the fish is harvested for human consumption directly, used in other applications or destructed” (NFSA pers. com., 2017). Below a certain fish weight, the salmon farmers will not be able to harvest and sell the fish to markets if they experience an ISA outbreak, and is consequently forced destruct the fish or sell the fish to producers of products such as salmon oil and pet food for processing (NFSA pers. com., 2017; Hordafôr, u.d.).

Previous literature on the economic implications of ISA

ISA has caused severe harm to the salmon farming industries in both Faroe Islands and Chile. On the Faroe Islands, ISA was first diagnosed in 2000. The disease caused major challenges for the industry between 2000 and 2005, with more than 33 outbreaks diagnosed. ISA insurance did not exist on the Faroe Islands during this period, and consequently increased the net losses for the industry (Lyngøy, 2002). The harvest volumes of Atlantic salmon on the Faroe Islands reached 47 ktonnes in 2003, before bottoming in 2006 at 12 ktonnes (Kontali Analyse AS, a, 2017). After 2005, ISA was not diagnosed on the Faroe Islands until March of 2017 (Bakkafrost, a, 2017).

In Chile, the first outbreak of ISA was reported in July 2007. From the initial outbreak, 230 outbreaks were diagnosed before October 2009 (Multiexport, n.d.). Norway experienced 29 ISA outbreaks during the same period. Given the long production cycle, the impact of losing fish individuals in all weight classes was significant (Asche, et al., 2010). Consequently, Chile went from harvesting 404 ktonnes of Atlantic salmon in 2008, to 130 ktonnes in 2010 (Kontali Analyse AS, a, 2017). The losses were estimated to amount to over 2 USDb, and 26.000 workers were laid off (Barrionuevo, 2011). Questions have been raised regarding the reactionary measures by the Chilean industry in the face of ISA outbreaks, particularly as studies had addressed the risk associated with the ISA elsewhere in the early 2000s (Asche, et al., 2010).

Limited literature has been published on the cost of ISA in addition to the discussion above. Cipriano & Miller (2003) reported that ISA outbreaks in 1999 cost the Norwegian industry 11 USDm and the Canadian industry 14 USDm. Vike (2014) reported that the average losses due to ISA outbreaks in Chile were between 15 NOKm and 25 NOKm per farming site (Cipriano & Miller Jr., 2002). In 2002, the NVI estimated that a typical outbreak of ISA in Norway cost on average 10 NOKm (Solsletten, 2008). All of these estimates are lower the simulated figures in the study, but it is worth cautioning comparing the figures directly, as the increase in salmon prices and costs alike will have increased the losses, given the same biological implications, since these assessments were completed.

3.3.5 Pancreas Disease (PD)

Pancreas disease (PD) is an important and serious viral disease for salmon fish farmed in the sea, caused by *Salmonid alphavirus (SAV)* (Hjeltnes, et al., 2017). PD is a notifiable disease in Norway. The disease was first discovered in Scotland in 1976, and has later spread to other countries in Northwestern Europe (Kristoffersen, et al., 2009). PD was first diagnosed in Norway in Hordaland and Sogn and Fjordane counties towards the end of the 1980s (Jansen, et al., 2015). The disease spread to Rogaland in 2004, and was diagnosed in Møre and Romsdal in 2006. A total of six subtypes of SAV virus have been described, although only two subtypes affect Norwegian salmon farming operations. Until 2010, only SAV3 had been diagnosed in Norway, when marine SAV2 was diagnosed in Central Norway (Jansen a, et al., 2015).

There are believed to differences in the mortality between outbreaks of SAV2 and SAV3 (Lillehaug, et al., 2012; Jansen a, et al., 2015). Jansen et. al. (2015) found lower mortality on sites that had been infected by SAV2, than SAV3 sites. 25% of the marine SAV-2 sites surveyed by Jansen et. al. (2015) observed PD-specific mortalities during a four-month period, while the corresponding figure for SAV3 sites was 72% (Jansen, et al., 2015; Jansen, 2013).

PD outbreaks occur throughout the year, but with an elevated incident rate during summer. Increasing seawater temperatures have been documented to affect the development of disease (Stene, et al., 2014). Central in the prophylaxis process is to stop transmission after detection of disease (Aukner & Haatuft, 2015), as the most important infection source for SAV is the presence of infected salmon in the sea (Hjeltnes, et al., 2017). Other important anti-disease measures include health surveillance, closed-valve transport of smolts and fish, and a coordinated fallowing regime covering large areas. There have been outbreaks of PD in recent years that can be traced back to long distance smolt- and fish transportation (Kyst.no, 2016). There are usually no external symptoms, but infected fish typically have reduced appetite, -growth and -condition. The disease first degrades and destroys the pancreas, which can lead to lower nutritional content in the harvested fish (Larsson, et al., 2012). Some fish that survive outbreaks can become “loser fish”, meaning that they are not able to utilize or absorb nutrition (Aukner & Haatuft, 2015).

PD became an increasing problem in Norway in the early 2000s. There are currently around 130-140 outbreaks of PD in Norway per year (Hjeltnes, et al., 2017), two thirds of which are SAV3 outbreaks. Hordaland is the county that has the highest number of SAV3 outbreaks, historically accounting for over half of diagnosed outbreaks. SAV2 primarily affects farms in Møre and Romsdal and Sør-Trøndelag.

PD regulation in Norway

PD has over the last years been regulated through two pieces of regulation. Following the spread of SAV3 to Møre and Romsdal in 2006, legislation to stop the spread of infection further north was introduced in 2007 (Hjeltnes, et al., 2017). The legislation introduced a "PD-zone" south of Hustadvika in Møre and Romsdal county. Within this zone, SAV3 PD was accepted as endemic. All outbreaks of SAV3 north of Hustadvika would result in measures aiming to eradicate the disease (Jansen, et al., 2015). This typically meant that farmers that experienced outbreaks either had to slaughter the fish pre-schedule ("stamping out"), or move the fish into the endemic zone. Following the introduction of SAV2 in Central Norway in 2011, a SAV2 specific legislation was introduced in 2012. This legislation also aimed to hinder SAV2 to spread further North than Sør-Trøndelag, and an administrative border at the Buholmsråsa Lighthouse close to the county border between Sør- and Nord-Trøndelag was introduced (Norwegian Food Safety Authority, 2017). In 2017, the NFSA introduced a common, nationwide, PD-regulation. The new PD-regulation removed "stamping out" as the primary option available to the NFSA when a PD outbreak occur in Nord-Trøndelag. The NFSA will now "evaluate the disease situation" before mandating a "stamping out" of sites north of Buholmsråsa (The Norwegian Government, 2017).

PD vaccine

There are approved vaccines against PD on the market, although the effect of the vaccination has been questioned (Hjeltnes, et al., 2017). However, studies have shown that vaccination against PD has a positive effect in reducing the number of outbreaks, and to decrease the mortality and fish downgrading at slaughter (Jensen, et al., 2012). Two companies, MSD and Pharmaq provide PD vaccines today. Prior to April 2017, a patent protected MSD's vaccine, before a ruling by the Norwegian Supreme Court removed the patent, and opened up for competition (Nodland, 2017).

PD vaccines are now integrated in multi-component vaccines, meaning that there is only need for one needle stick to also vaccinate the fish against PD. This means that the smolt producers reduce handling and impose a lower stress load on the fish. Historically, due to natural constraints and a starving period related to vaccination, the smolt producers have had a time challenge to complete two rounds of vaccination of the S0 generation (Vaccine producer pers. com., 2017).

Nearly all fish released south of Hustadvika are currently vaccinated against PD (Vaccine producer pers. com., 2017). However, there has been a lower demand for PD-vaccines from farmers in the Trøndelag counties. Given that the effect of the vaccine is dependent on a high share of the population being vaccinated and the clinical implications of SAV2 are perceived to be lower, many Trøndelag-based famers have decided not to vaccinate the fish against PD (Vaccine producer pers. com., 2017). However, the new PD-regulation will require that all salmon that are transferred to sea between Fræna in Møre and Romsdal and Sømna in Nordland are vaccinated against PD (The Norwegian Government, 2017; Grindheim, 2017).

Previous literature on the economic implications of PD

Most studies on the cost of PD has focused on site-specific calculations, instead of aggregated figures. This is mostly likely due to significant variations in mortality, reduced growth and other outbreak-specific characteristics, and the complexities of gathering the adequate data.

Aunsmo et. al. (2010) discussed the direct costs associated with PD outbreaks in Norway. They estimated that with 0.5 million smolts at a given site, and with the salmon prices at the time, costs of 15.6 NOKm could be identified at a farm level. Pettersen et. al. (2015) completed a similar exercise, though with a farm size of 1 million smolts and updated salmon prices, and found costs equal to 55.4 NOKm on a site level. Pettersen et. al. (2015) also included the preventive cost associated with functional PD-feed, which accounts for some of the increase.

Some studies have quantified the aggregated economic losses related to outbreaks of PD, although with impactful simplifications. Ruane et. al. (2008) estimated the cost of PD to the Irish salmon farming industry, although the methodology was not clearly specified (Pettersen, 2016). Torrissen (2008) approximated the annual cost of PD in Norway on an aggregated level to be 1 NOKb. Hagen et. al. (2016) presented a simple framework for assessing total PD-costs in Norway, by using earlier published analysis on a site level, and aggregating the figures up by the number of recorded outbreaks, estimating a total cost for the Norwegian salmon farming industry between 1.5 NOKb and 5.5 NOKb.

4. Theoretical fundament

Chapter 4 presents the theoretical fundament relevant for this study. This study falls within the research field of animal health economics. Section 4.1 presents an overview of the research field, including the development of the field and key considerations within the field. This section provides the reader with a background of the research field, and a general discussion of considerations related to disease in farming operations. Section 4.2 presents the framework utilized in researching the problem. This section presents different components of the model, and highlights similarities to other applications. Section 4.3 discusses the implications of diseases in salmon farming, in light of literature related to the optimization of fish farming operations. Disease outbreaks can adversely affect the optimization of production schedule in salmon farming, and the section debates such considerations.

4.1 Animal health economics

Animal health economics provide a key literature fundament for the analysis in this thesis. Economics is the study of "making rational choices and decisions in the allocation of scares resources for the achievement of competing goals" (Pettersen, 2016). Animal health economics can be described as "the discipline that aims to provide a framework of concepts, procedures and data to support the decision-making process in optimizing animal health management" (Dijkhuizen & Morris, 1997). According to Randolph et. al. (2003), animal health economics arose in the 1960s and 1970s following periods of significant scientific development, arguing that both epidemiology and economics were "part and product of this optimism". The rise of veterinary epidemiology was fueled by breakthroughs in human medical epidemiology. However, while human epidemiology aims to ultimately reduce the loss of human life, veterinary interventions concern themselves with changes in production costs and profits, creating an inevitable need for a specific area within economics. Additionally, Putt et. al. (1987) reasons that development of new and expensive disease control technologies created an important resource allocation decision for both animal owners and veterinary policy makers.

There are particularly two applications of decision-making in animal health economics (Randolph, et al., 2003). The first addresses societal-level decision-making. This can for instance include economic justification of national measures to eradicate epidemic disease or protect from their introduction. Such studies are for instance the examination of the value of veterinary services, illustrated by Roger S. Morris’ (1969) assessment of the value of veterinary services to primary industries, and Hagen et. al.’s (2016) analysis of the value of the Norwegian Veterinary Institute’s (NVI) effort within fish health. The second category of decision-making focuses on improving farm management in commercial production systems (Randolph, et al., 2003). Applications within this field can range from “assessments of whether a veterinary operation would be financially profitable to carry out, to sophisticated multi-year models based on epidemiological simulations” (Randolph, et al., 2003).

All farm operations have the challenge that they are farming live creatures, and consequently have to optimize and control the biological situation and -process of the farm animals. Common for all farm operations with farm animals, especially those that do not yield outputs during the production process, is that they have significant build-up of working capital. A disease outbreak can therefore cause significant economic- and productivity challenges for the farmer. Dijkhuizen & Morris (1997) describes the underlying challenge with infectious and parasitic disease in farming operations as there being a “disease agent that is in constant competition with its host for access to nutrient supplies”. The disease agent is successful if “it can divert for its own use and reproduction, nutrients which the animal would otherwise have used for growth and production”. Dijkhuizen & Morris (1997) list three arguments on how disease may alter animal productivity:

- *Effects on ingestion:* many diseases can alter feed intake in the affected animals. In most cases the intake is reduced. Pain, mechanical difficulty, affected locomotor ability or reduced appetite due to discomfort, can cause the lower intake.
- *Effects of disease on feed digestibility:* some diseases can also alter the affected animals’ ability to digest feed.
- *Effects of disease on physiological processes:* diseases can modify many different physiological processes, such as nutrient metabolism, respiration and excretion.

Dijkhuizen & Morris (1997) further describes how the “functional derangements” outlined above translate into measureable economic effects for a farm operation:

- *Premature death:* The economic effect of mortalities is measured as the difference between the market value of the animal and the value when dead, less the cost that would have been incurred in obtaining the market value.

- *Changed value of animals and products from slaughtered animals:* Diseased animals may have a lower market value. This can be caused by visible lesions or due to indirect changes in appearance or body confirmation.
- *Reduced live weight gain:* Studies have shown that sick animals can gain weight more slowly than equivalent disease-free animals. This means that the farmer will either have to a) slaughter the animal at a lower weight on schedule, or b) increase the length of the production cycle to obtain the desired market weight (which leads to weaker capacity utilization).
- *Reduced yield and quality of products:* Disease can influence, for instance, milk- and egg yields. The quality of products may also be reduced.
- *Altered feed conversion efficiency:* Disease can affect animal productivity by altering the metabolic processes for protein and other nutrients. This reduces the feed conversion efficiency of the affected animals, and consequently the productivity. Feed conversion efficiency is a preferred measure for how disease affects the animals.

4.2 Economic losses in domesticated farming operations

Dijkhuizen & Morris (1997) describe animal disease as “an influence which affects the resource transformation process, and results in extra resource use and/or fewer animal products than before”. These effects are referred to as direct effects, the monetary estimate of which is referred to as direct costs. Additionally, there could also exist indirect effects, as disease in farm animals can affect parts of the economic system and thus have diminishing benefits to people. In order to understand the scope and implications of diseases, quantification of economic losses associated with animal health and -diseases is therefore important for decision making processes related to both farm- and national policy management. Bennett (2003) notes that the magnitude of disease losses do not by themselves necessarily equate to priorities for research or for the allocation of resources to treatment or control. However, “estimates of the costs associated with disease are valuable economic information which, at the very least, gives some idea of the magnitude of the benefits that could be gained from eliminating or reducing disease impacts”. Dijkhuizen and Morris (1997) support this view and argues that the calculation of economic losses is “not only important for a description of the actual situation, but also for how, and to what extent it can help to answer question such as: how to limit the losses as much as possible, in what way and to what extent can the risk of disease be diminished, how much loss can be avoided, and what efforts and costs are involved”.

Bennett (2003) described that sources of economic losses associated with disease outbreaks can be summarized in two categories, an output loss, and additional input use. The output losses arise as the farmer experience losses of output through for instance mortality, regulatory mandated pre-scheduled harvesting and lower growth post outbreak. Bennett (2003) further describes that in order to quantify monetary output losses, the implications of disease must be quantified by comparing the actual situation against an “attainable” situation without disease. Secondly, farmers that have the option to increase their use of inputs such as feed and veterinary inputs might do so to control, compensate for or mitigate the consequences of outbreaks. Subsequently, the farmers will incur more costs to reduce the implications of the outbreak related losses. In salmonid farming, this is particularly the case for PD outbreaks within the endemic areas, as the farmers can extend the production cycles in an attempt to reach the planned or optimal harvest weights.

4.2.1 Methodological approaches for quantitative assessments of animal disease

A framework for assessing direct costs associated with disease was described by McInerney (1996) (Bennett, 2003). The direct costs associated with disease, C, has two economic components, loss, L, and expenditures, E. Loss is defined as the direct effects of disease on farm output, including losses associated with mortalities, referred to as output loss in the preceding section. Expenditures, or increased input use, compromise the extra resources needed due to disease, ranging from feed to veterinary inputs. The direct costs associated with disease can thereby be defined as:

$$C = L + E \tag{1}$$

A common assumption in economic literature is that producers are profit-maximizers (Pettersen, 2016). Consequently, the objective for farm management is to minimize C. Bennett (2003) expands this framework to be expressed as:

$$C = (L + R) + \ T + P \tag{2}$$

Where L is defined as the value of the loss in output associated with the disease. R is defined as the changes in expenditures related to non-veterinary resources due to the disease, including changes in feed costs and farm labor. T is the cost of inputs that are used to treat the disease, while P is the incurred cost of disease prevention. For decision making when experiencing diseases, minimizing C gives the optimal economical solution to the challenge provided by the disease. In some applications, the total costs of experiencing a disease outbreak will be negative (adds costs), and is therefore commonly referred to as economic losses throughout this study.

There are several analytical tools available for the relevant economic analysis in this project. Enterprise budgets and gross margin analysis are both established techniques for evaluating profits (Dijkhuizen & Morris, 1997; Pettersen, 2016). Enterprise budgets provide an understandable measure of the profitability of production activities at an enterprise level (Engle, 2010). Enterprise budgets are a static model to evaluate, given certain assumptions, if an enterprise as a whole is profitable. However, the fact that enterprise budgets are constructed on an aggregated level, means that they will not have "answers for any particular farm" (Engle, 2010). The challenge of allocating overhead and other SG&A costs effectively to each farm creates a need for other techniques (Dijkhuizen & Morris, 1997). One such technique is to develop the budgets on a gross margin form. This technique initially only focuses on the specific costs allocated to the individual farms (Dijkhuizen & Morris, 1997), and only later includes fixed overhead costs. This thus provides a better assessment of differences in productivity and profitability between farms. If the economic analysis concerns a specific *change* in the production, e.g. a disease, partial budgeting can be applied (Pettersen, 2016; Engle, 2010; Dijkhuizen & Morris, 1997).

4.2.2 Partial budgeting

To estimate the cost,C, of disease outbreaks described in the preceding section, partial budgeting can be utilized. Partial budgeting is a method of economic analysis that is particularly useful when the proposed analysis focuses on a simple economic comparison of disease control measures or -implications on a specific farm, rather than on an enterprise level (Dijkhuizen & Morris, 1997). Partial budgeting is a technique that quantifies economic consequences of a specific change on a given farm (Engle, 2010; Roth & Hyde, 2002). Dijhuizen & Morris (1997) describes the framework as optimal when assessing the change that will occur in "farm profit from a change in operations". A partial budget can be used to evaluate both potential decisions and review ex-post consequences. Dijkhuizen & Morris (1997) describes a partial budget to comprise of four sections, three of which are relevant for the analysis in this thesis:

1. *Reduced variable costs:* cost items that would be avoided in the new operational plan, that would have been incurred under the original plan.

2. *Returns foregone:* items of return that would have been received without a change in the farm's operational plan, but not with the change in the operational plan.
3. *Extra variable costs:* cost items that will be incurred in the new operational plan, that would be avoided under the original plan.

The bottom line of the partial budget is called the change in economic benefit, and is a measure of whether net returns would increase or decrease by making the proposed change and by how much (Engle, 2010). This estimate is derived as the difference between the economic profit for a production cycle with disease, compared to a production cycle with an "attainable" level of disease. This comparable production cycle is estimated through the definition of a control group. This control group is defined based on criteria and characteristics that are shared between the site experiencing the viral disease outbreak, and sites with levels of disease challenges at an "attainable" level. The monetary losses quantified in the partial budget therefore represents the difference between the realized scenario and a "what-if" scenario for the particular site experiencing a viral disease outbreak. If the change in net benefit is positive, then the proposed change should be implemented or was beneficial for the farm's probability, and vice versa. However, in certain scenarios, all of the available alternatives or outcomes will have/have had a negative change in net benefit.

One drawback with partial budgeting is that it is limited to analysis of only two alternatives at a time (Engle, 2010). Separate budgets need to be set up to analyze a series of changes. Secondly, partial budgeting analysis requires substantial amount of data and thorough record keeping. This can for instance include biological production data, sales data, labor records and procurement (Engle, 2010, p. 128). This can be a complex and costly effort for many, particularly, smaller farming companies. Another important aspect of partial budgeting is that it does not account for the time value of money, as the method does not include discounting (Rabin, et al., n.d.).

Partial budgeting can be applied ex-post, to assess the net benefit or direct costs (-losses) of an action or change in production plan that has already been completed or implemented. A partial budgeting framework is therefore utilized for analysis of the effects on economic profit (loss) of viral disease outbreaks in this thesis. Several other studies within salmon aquaculture have utilized partial budgeting, researching both the losses associated with specific diseases and the benefits of control. Lillehaug (1989) researched the cost-effectiveness of different vaccination methods.

Menzies et. al. (2002) researched the direct costs associated with cataracts. Brun et. al. (2003) described the direct financial losses associated with CMS among farmed Atlantic salmon in Norway. Thorarinsson & Powell (2005) studied the economics of fish vaccination. Aunsmo et. al. (2010) described the direct costs associated with PD outbreaks among farmed Atlantic salmon in Norway. Pettersen et. al. (2015) described the economic benefits of disease triggered early harvest relating to PD in farmed Atlantic salmon in Norway. Chapter 3 presented a discussion of some of these studies.

4.2.2.1 Model framework

Based on the theory presented above, the study implements a stochastic partial budgeting model as the analytical model, after being adapted to be applicable to the salmon farming industry and the desired analysis. Each respective farm is the unit of economic analysis (Stock & Watson, 2015). Similar adaptation has been utilized by Aunsmo et. al. (2010), who modified the framework described by Bennett (2003) for quantifying direct economic costs associated with disease. Bennett's original framework for quantifying economic losses was expressed as:

$$C = (L + R) + T + P \tag{2}$$

while the modified framework utilized by Aunsmo et. al. (2010) for describing direct economic costs (DC) was written as:

$$DC = BL + EC + T + P - I \tag{3}$$

The modified equation's components are cost of biological losses (BL), extraordinary costs (EC), costs of treatment (T), costs of prevention (P) and insurance payout (I). All of the added components are relevant for describing total direct costs associated with viral disease outbreaks in salmonid farming, and will be discussed in detail in section 5.2. The biological losses (BL) was further defined based on three of the four sections in Dijkhuizen and Morris' (2003) framework:

$$BL = Rf + (Ce - Cr) \tag{4}$$

Where Rf is the foregone returns, Ce is the extra variable costs, and Cr is the reduced variable costs. To summarize, the entire framework for assessing the economic losses associated with outbreaks of disease can be expressed as:

$$C = Rf + (Ce - Cr) + T + P - I \tag{5}$$

As will be highlighted further in section 5.3.2, the thesis will only focus on the viral diseases PD, ISA and CMS when estimating economic losses. This limitation is due to data with a satisfactory level of details only being available to the project for these three diseases.

4.3 Optimizing farming processes of salmon

Salmon farming is a time- and capital consuming process that is highly regulated, and thus the overall production process have restrictions related to how frequently the salmon can be harvested. Accordingly, the industry has a problem of rotation that needs be optimized for each company and farming site continuously. Much of the theory developed for optimizing the processing process of salmon aquaculture has been developed from the field of forest management and agriculture (Guttormsen, 2008). German forester Martin Faustmann is widely accredited to be the founder of this research field (Samuleson, 1976). Faustmann was the first to suggest and solve the optimal rotation for a forestry operation, using principles of discounting (Asche & Bjørndal, 2011). Faustmann's principles have also in studies within forest management been extended to account for the implications of disease on rotation, such as Macpherson et. al. (2016). There are several studies that analyze the optimal production adaptation for a salmon farmer. Bjørndal (1988) developed and described a model to locate the optimal timing for harvest of farmed fish. Guttormsen (2008) extended the solution to also incorporate the fallowing period, as a key assumption in Bjørndal's (1988) application is that a new generation can be re-stocked immediately.

When a salmon farmer experiences disease challenges, the optimal rotation point can be affected as the use of input factors and generation of outputs can be altered from the original production plan (Marine Harvest, 2017). For PD, for instance, it is common for the salmon farmers to extend the production cycle when experiencing an outbreak[3], and thus the production cycle will be extended past the original optimal rotation point. Diseases in salmon farming, and particularly PD, will thus impact the capacity utilization of each site as the cycles no longer follows an optimal rotation schedule.

[3] Historically in areas within each of the endemic PD-zones.

5. Method and data

Chapter 5 presents the method and data utilized in the thesis. In section 5.1, the chapter presents the overall model and the performed analysis. This section will debate the fundamental principles of the simulation model, and further present some of the underlying practices of reporting output from the simulation model. Section 5.2 discusses each of the model components included in equation 5 in the preceding section. Viral diseases can have varying impacts on farm biology and –profits on a case-by-case basis, referred to as the biological losses in this study. The section therefore discusses biological losses in light of the different potential scenarios that can materialize in an outbreak. Further, the section discusses each of the other components of the framework, and what direct costs and benefits that can arise within each of them. Section 5.3 presents the data utilized in the simulation model. The penultimate section, 5.4, presents the control group utilized in the simulations to estimate the biological losses portion of the framework. The section shows the analysis performed to construct the control group, and the resulting definition of the control group. Finally, the last section of the chapter presents the assumptions utilized in the model, both the motivation behind the assumptions and the implications of them.

5.1 Model construction and output

To research the problem in the thesis, the study developed a stochastic analysis model with components of partial budgeting. The simulation model was constructed to estimate the direct costs associated with each viral disease outbreak included in the simulation model, with a breakdown for the five components presented in Equation 5. This methodology of developing and presenting results have previously been utilized by both Aunsmo et. al. (2010) and Pettersen et. al. (2015).

Given that certain model parameters are uncertain, and that the implications of viral diseases can vary between outbreaks, the model utilized probability distributions for some of its model components. The simulation or trails, of these probability distributions thus yielded estimates that indicated a range of values, rather than a concreate estimate of only one value.

The simulation model was developed to run two separate sets of simulations. The first estimated the economic profit of the sites in each control group. The control group only consisted of sites without viral disease challenges. The economic profit of these sites were later averaged based on filters discussed in section 5.4, to estimate the economic profit of the control group.

The second simulation estimated the economic profit, prevention-, treatment-, other additional costs, and insurance payout of the sites affected by outbreaks. The difference between the economic profit of the control group and each outbreak yielded the estimated monetary biological losses for that particular outbreak.

All estimates, both in the first and second simulation, were estimated as the net EBIT (Earnings Before Interest and Tax) after harvest cost, yield loss and site-specific maintenance cost, but excluding post-processing transportation and general SG&A costs. A salmon price adjusted to a free-on-board (FOB) packaging plant measure had to be utilized, as the costs were estimated of a FOB packing plant basis.

Both simulations used the same inputs and model components. The number of sea lice treatments and release of cleaner fish for each respective site was included in the model. Each simulation used monthly salmon sales data corresponding to the correct month of harvest and the correct weight class of the harvested fish. All harvest volumes was converted from WFE to HOG based on a conversion table (Kontali Analyse AS, a, 2017), to standardize with the salmon price quotes. All of the non-outbreak related cost inputs were the same in both simulations.

The method for allocating losses allocated the economic losses to the year the fish was harvested or disposed of. This is accordance with the matching principle in accounting regulations (Lovdata, 1998). The matching principle says that a company should only acknowledge an expense in the same period as the corresponding revenues. For salmon farmers, that means that the expenses on each income statement reflect the release of built-up costs for the particular generation that was harvested during that accounting period. When presenting the results, however, the estimates for each outbreak was reported to the year the disease was detected, to align the estimates with outbreak statistics and to be easier to relate to for the reader.

The costs of mortalities were carried by the harvested individuals up until harvest, in accordance with industry practices (Marine Harvest, 2017). In the model, a site experiencing an outbreak that required the depopulation of the entire site pre-schedule, the losses were acknowledged in the year of the harvest, even though the economic performance could be compared to that of a control group being harvested up to a year later[4]. Therefore, utilized sources that report cost parameters for a

[4] Dependent on the stage in the production cycle. Early pre-scheduled harvest means longer time until scheduled.

particular year’s harvest were converted back to the correct release generation, further discussed in the succeeding section.

The output from the simulation model provided estimates of the direct costs associated with viral disease outbreaks at each of the sites experiencing an outbreak, with an overview of each of the cost categories, for all percentiles between 5% and 95%. Chapter 6 presents and discusses these estimates.

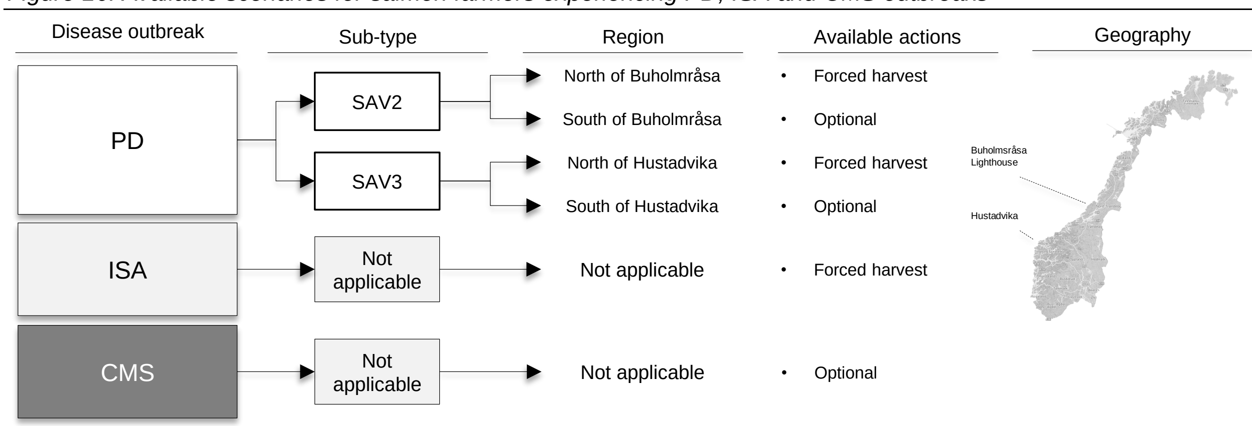
5.2 Model components

The following section will discuss each of the components in the full framework presented in equation 5, and relate each component to the analyzed viral diseases directly.

5.2.1 Biological losses

Biological losses was reported to be the most important driver for direct costs associated with PD outbreaks by both Aunsmo et. al. (2010) and Pettersen et. al. (2015). Multiple different scenarios for biological losses can materialize when a salmon farmer experiences an outbreak of PD. This has historically been dependent on the geographic location of the farming site, the current regulation in that area and decision-making. Fewer possible scenarios can materialize when farmers are experiencing outbreaks of ISA and CMS. Figure 16 summarizes the plausible scenarios, and thus the plausible scenarios for biological losses.

Figure 16: Available scenarios for salmon farmers experiencing PD, ISA and CMS outbreaks



Source: Author creation based on various sources

The following section provides a discussion of some of the drivers behind the quantified biological losses, based on the framework presented in the preceding section. Given the potential differences in outbreak characteristics and implications between the diseases, and also among outbreaks, some aspects of the framework will not be applicable to all of the scenarios.

Returns foregone

Lower fish growth

An important implication of PD outbreaks is that the farmers experience reduced growth post-outbreak (Pettersen, et al., 2015). Aunsmo et. al. (2010) found a 0.6 correlation between reduced growth post PD outbreak and the biological feed conversion ratio (bFCR). Farmers experiencing PD outbreaks can counter-act this, if they are within the endemic PD-zone, by increasing the length of the production cycle. Previous expert panels have indicated that compensation for reduced growth through extended production cycles in the endemic SAV3 zone happens frequently (Aunsmo, et al., 2010). The implication of reduced growth and extended production cycles can be higher production costs driven by a higher FCR, and weaker capacity utilization through delayed rotation of stocks.

Fish mortalities

PD, ISA and CMS can cause fish mortalities, although with varying degree of severity. Mortalities during the production cycles both affect the farmer through lower harvest volume, but also by increasing the cost of production for the remaining individuals, as they have to carry the accumulated costs incurred by the diseased individuals. The implications of mortalities are offset by the disappearance of additional required variable cost to grow the fish to harvest size.

Lower harvest volumes

When a farmer experiences an ISA outbreak, an important implication for the farmer is that he has to slaughter or dispose of the fish quickly. Dependent on the stage in the production cycle, this can amount to significant foregone volumes for the farmer. Similarly, if a farmer does not alter his production plan when experiencing a PD outbreak, or the fish contracted a SAV subtype outside of the respective endemic areas, harvest volumes will be impacted negatively.

Impact on sales price and downgrading

PD outbreaks can affect the obtained salmon price, as a higher share of fish can be degraded to non-superior quality categories (Aunsmo, et al., 2010). This is mainly due to a discount caused by lower flesh quality (Asche, b, 2016). This thus lowers the value of the harvested biomass, and increases the economic losses of experiencing an outbreak. Additionally, fish that is taken out of the production cycle below optimal harvest weights typically obtain a lower sales price than fish of “normal” harvest sizes, as explained in section 2.3. This has the implication that there is definable break-even point for whether the farmer should harvest the fish pre-schedule or to allow the fish to grow to desirable harvest size when an outbreak emerge (Pettersen, et al., 2015).

As discussed in section 3.3.4, fish diagnosed with ISA can only be sold if they have reached a satisfactory harvest weight. If the fish has reach this weight, the sales price is not impacted by the fish's proximity to an ISA outbreak. If the fish has not reached a satisfactory harvest weight, the fish material can be sold to silage producers for processing into other products or destructed (NFSA pers. com., 2017). Therefore, for outbreaks were the harvest weight is not satisfactory, the only potential salvage value of the fish is the price the farmer can obtain from the sale of his biomass to silage companies.

No salmon price downgrades were quantified for CMS, as the implications of CMS outbreaks are typically confined to implications related to mortality (Salmonid farmer, a pers. com, 2017).

Change in variable costs

Feed costs

In cases where the fish have experienced a viral disease outbreak and the post-outbreak growth is impacted, the farmer may opt to extend the production cycle to account for the lower growth and allow the fish to reach optimal harvest size. This can lead to higher feed costs driven by a lower bFCR, as the fish needs more feed to reach the desired harvest weight.

In cases where the fish have been harvested pre-schedule, initiated by either the NSFA or the farmer, fish no longer need to be fed for the full duration of the production cycle. This reduces the variable costs associated with feed. This is particularly the case for outbreaks of ISA, when the NFSA mandates the farmer to remove the fish from the site. Historically, this has also been the case for cycles that developed a particular subtype of SAV outside of the respective endemic area.

Sea lice mitigation cost

Extending the production cycle following an outbreak can require the farmer to increase the number of sea lice treatments planned for that production cycle in order to comply with the NFSA limit for sea lice. Additionally, due to high mortality among cleaner fish (Poppe, 2017), the farmer may also need to increase the release of cleaner fish if he extends the production cycle.

A production cycle that is concluded pre-schedule may have a reduced need for sea lice treatments and cleaner fish, which reduces the variable costs associated with these activities

Insurance premiums

As explained in section 2.5, the standing biomass of each pen throughout the production cycle dictates the insurance premiums. Consequently, if the biomass on the site is reduced due to, for instance, pre-scheduled harvest, mortality or lower growth, the insurance premiums are also lower for the farmer than it would be in an “attainable” production cycle.

5.2.2 Costs of prevention

Vaccine

Fish can be vaccinated against both ISA and PD, and this is therefore a source of prevention costs for the respective diseases. These costs can be estimated through the cost of each vaccine dose and the estimated probability of a particular fish in a particular area being vaccinated.

Other prevention costs

Pettersen et. al. (2015) described that salmon farmers working to improve management of viral disease outbreaks also have prevention costs associated with “implementation of protocols for biosecurity”, and “depreciation costs of specific investments in measures on the land base, boats and the sea site”. These biosecurity measures include for instance “’all in, all out’ production, depopulation, disinfection of personnel and equipment, fallowing, and movement restrictions” (Pettersen, 2016). These costs are not only applicable in the control of SAV subtypes, but also for other viral diseases, including ISA and CMS.

5.2.3 Costs of treatment

The cost of PD-treatment is the cost of using functional PD-feed during outbreaks (Pettersen, et al., 2015). As discussed in section 3.3., no treatment options are available for ISA and CMS. Therefore, the study did not include any treatment costs related to ISA and CMS outbreaks.

5.2.4 Extraordinary costs

Extraordinary labor costs

When farmers experience outbreaks of viral diseases, extraordinary labor costs can often be incurred to meet the internal and external requirements for operations such as mortality handling (Aunsmo, et al., 2010; Pettersen, et al., 2015). This includes the need for a quick response to ISA outbreaks, were the NFSA can mandate the depopulation of the site within a couple of weeks. Outbreaks can therefore lead to extraordinary labor costs related to both current employees and hired labor to complete certain operations at each farming site.

Harvesting cost

Extraordinary harvesting costs might emerge during outbreaks. This can include operations such as compliance with cleaning- and disinfection protocols imposed by the NFSA for wellboats and slaughtering facilities handling sick or disease-affected fish.

5.2.5 Insurance payout

The insurance payout for salmon farmers experiencing viral disease outbreaks can vary based on the policy they have with their insurer, the extent of the mortalities and dependent on the disease. A typical biomass insurance policy only allow for mortality related claims when pen specific mortality surpasses 30% over a three-month period (Insurance company pers. com., 2017; Aunsmo, et al., 2010). Therefore, dependent on the severity of a site's pen mortalities, an insurance policy may not pay out when a farmer is experiencing a viral disease outbreak.

On top of regular biomass insurance, farmers also purchase remediation insurance against ISA (Insurance company pers. com., 2017; Gangdal, 2017). These insurance policies become active for farmers that experience an ISA outbreak, but the fish has not yet reached satisfactory harvest weights. The remediation insurance policy, therefore, mitigates some of the losses for the farmer when he has to destruct ISA-fish instead of the selling it to the markets for consumption. The net insurance payout is adjusted for a deductible share, which is typically high for these policies. Additionally, these insurances also include a component to cover extraordinary cleanup costs limited upwards to 1.2 NOKm (Insurance company pers. com., 2017). This component is not dependent on the site of the farming site. These insurance policies are typically only active until the fish reaches 2.6 – 3.0 kg, as the fish will by then be harvest- and saleable (Insurance company pers. com., 2017). There are no available insurance policies for any other viral diseases than ISA.

Table 1 provides a summary of the different components included in the analytical model based on the discussion above and a similar table presented by Pettersen et. al. (2015).

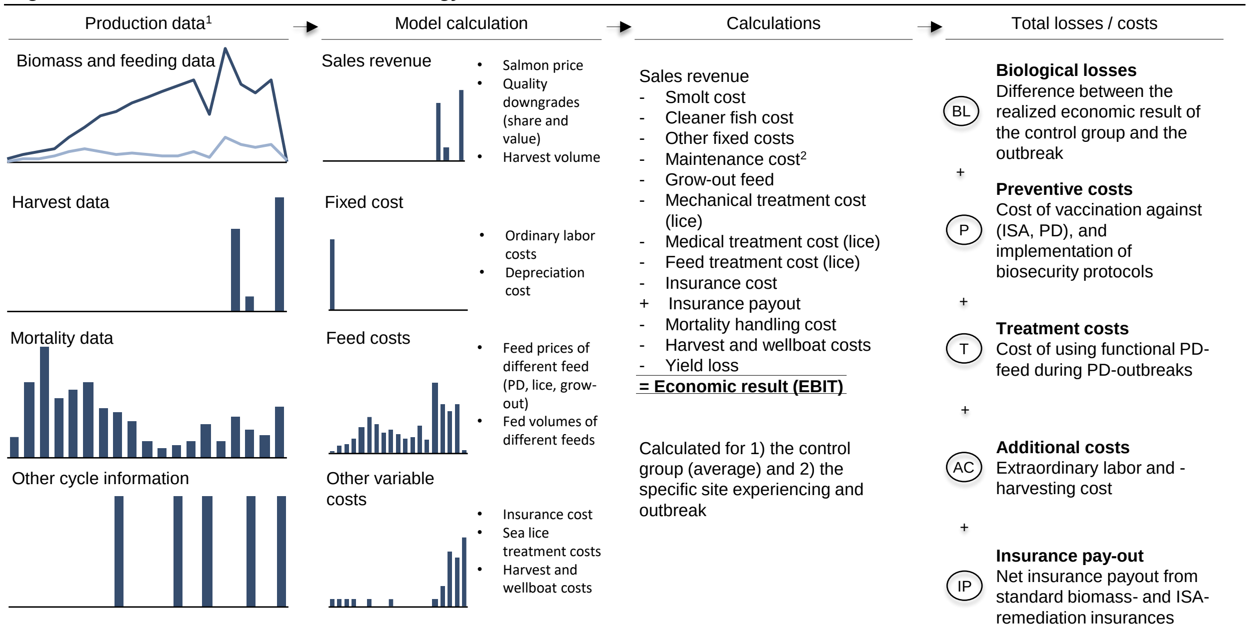
Table 1: Description and overview of model components

Model component	Description
Biological losses	Lower fish growth, mortalities, reduced sales price and downgrading, lower harvest volumes
Prevention cost	PD-/ISA-vaccine, biosecurity protocols/preventive measures
Treatment cost	Functional PD-feed
Extraordinary costs	Extraordinary labor cost, mortality handling, extraordinary wellboat and slaughterhouse costs
Insurance payout	Insurance payout to compensate for mortalities and ISA remediation insurance

Source: (Pettersen, et al., 2015; Aunsmo, et al., 2010; Author creation)

Figure 17 summarizes the model framework presented in this section. Production data was used to simulate the biological process of each production cycle, which together with the cost- and sales inputs facilitates the estimation of the economic result of each production cycle in both the control group and for each cycle experiencing an outbreak. Appendix 2 provides a detailed overview of the model components discussed and displayed in Figure 17.

Figure 17: Overview of model methodology



Notes: 1. Production data displayed is illustrative data from a particular production cycle at a particular farming site. 2. Cycle and site-specific maintenance cost only

5.3 Data

The following section presents the data utilized in the simulation model, firstly the process of gathering the data, and secondly an overview of the data utilized.

5.3.1 Data gathering methodology and sources

Primary sources

Quantitative data is usually the preferred source of data for sound decision-making and analysis. However, those kinds of data sources might not be available. Given that disease outbreaks in salmon aquaculture have a lack of concrete published data on cost and sales parameters, the only way to elicitate quantitative data is from a heterogeneous expert panel (Van Der Fels-Klerx, et al., 2002; Aunsmo, et al., 2010). An expert panel was invited to participate as sources for inputs in this thesis, based on a protocol suggested by Hoffmann et al. (2007) and Van Der Fels-Klerx et. al. (2002), and utilized by Aunsmo et. al. (2010) and Pettersen et. al. (2015). 26 representives from the same number of Norwegian farming companies were inivited to participate in the expert panel. All companies were identified as companies that experienced a PD and/or ISA outbreak on more than three respective farming sites since the start of 2012. Seven of the invited representatives replied, but, ultimately, one company agreed to participate in the expert panel in time to be included. This company had experienced approximately 3% of all PD outbreaks included in the analysis model (BarentsWatch, n.d.).

The company was asked to provide up to three answers for each question, namely “minimum”, “most likely” and “maximum” answers, to allow for construction of PERT-distributions in the simulations. A similar approach was utilized by Aunsmo et. al. (2010) and Pettersen et. al. (2015). A PERT-distribution, a version of a beta distribution, is a continuous probability function frequently used when modeling answers from expert panels (Vose, 2010, p. 673). A full overview of the utilized questionaire is displayed in Appendix 3.

Even though efforts were attempted to increase the number of participants, the limited number of participating experts was deemeed to not be sufficent to be used solely as the source for inputs in the model, so triangulation against published sources was in most cases completed to compare the obtained answers. This to ensure that the inputs alligned with more extensive expert panels or other published sources, and will be highlighted further in the suceeding section.

In addition to the farming group representatives, representatives of other companies in different segments of the value chain provided either data or information through interviews. Appendix 4 shows a sanitized overview of these sources.

Secondary sources

The project has also utilized secondary sources for gathering data and inputs. The discussion of inputs and data in section 5.3 presents and cites these sources.

5.3.2 Production data

The following section presents the two datasets of production data used to build the simulation model and other model inputs. Firstly, the biological production data used to simulate the biology in each production cycle, and secondly the viral disease outbreak data used to identify production cycles with viral disease outbreaks. Lastly, sea lice treatment data for each production cycle and other production costs and sales inputs are presented.

5.3.2.1 Biological production data

Biological production data was obtained from the Norwegian Directorate of Fisheries (NDF) for all Norwegian marine salmon farms over 2012 – 2016 (Norwegian Directorate of Fisheries, 2017). Norwegian aquaculture companies operating seawater grow-out sites have to monthly report biomass parameters such as biomass, harvest volumes, and feed consumption (Lovdata, 2008), and these figures were utilized to estimate the biological process in each simulation. This data set has previously been described as crude, and the quality is impacted by errors and missing data (Pettersen, 2016), which can challenge the validity of the dataset and simulation results. Despite the shortcomings of the data, the data is believed to be the best dataset available to this project, and above all better than simulated figures. 2063 production cycles were identified within the production data, including cycles operated with research-, exhibition- or broodstock licenses. Production cycles refer to the period of time in which a particular generation is stocked at a specific farming site. The production cycles were identified by analyzing each farming sites' biomass data, and defined to last between each fallowing. 129 of these production cycles was excluded as the sites operated with research, broodostock or exhibition licenses. The included cycles were from 933 unique farming sites. Figure 18 provides a macro perspective view on the production cycles included in the analysis model.

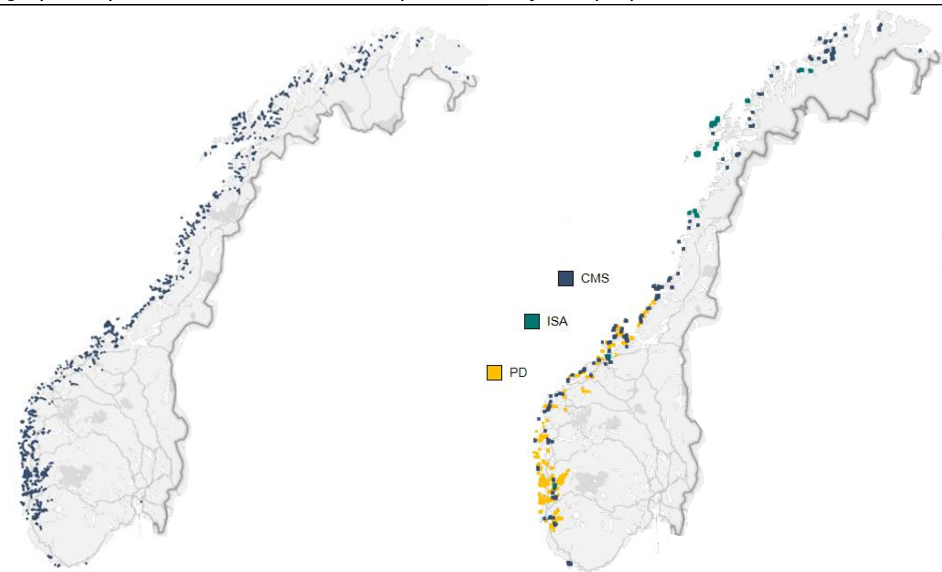
Publishing restrictions govern the production data. Therefore, the data will not be presented throughout the thesis in such a way that allows for the identification of specific companies or farming sites. Appendix 5 provides an overview and key statistics of the production data utilized for the simulations.

5.3.2.2 Viral disease outbreak data

Each respective site's outbreak history associated with PD and ISA was collected from BarentsWatch Fiskehelse (BarentsWatch, n.d.). Data from BarentsWatch was used to calculate the timing of both the suspected and proven outbreaks of PD and ISA at a site level between 2012 and 2016. Additionally, the Norwegian Veterinary Institute (NVI) provided CMS outbreak data for 2012 - 2016 (Norwegian Veterinary Institute, c, 2017). As the production data only covers the years between 2012 and 2016, only the outbreaks affecting the generations between the S12012 and the S02016 could be included in the outbreak list, as the production data did not allow for analysis of cycles that started before 01.01.2012. This means that the simulations will only provide a complete annual overview for 2014 and 2015.

In total, 526 outbreaks of viral diseases were included in the simulation model. Of these, 316 were PD outbreaks, 37 ISA outbreaks and 173 CMS outbreaks. Outbreaks on sites that operate with research-, exhibition- or broodstock licenses were excluded. The scope of the study focused on regular grow-out sites as the other licenses have a different business model, including testing of scientific concepts and sale of eggs, respectively. Furthermore, only proven outbreaks were included in the simulations. The timing of each of these outbreaks was overlaid with the production data, to ensure that they were allocated to the correct production cycle. For 2014 and 2015 combined, the included outbreaks included 80 %, and 92 % of the reported outbreaks of PD and ISA. Appendix 6 provides an overview of the outbreaks that are included in the simulations.

Figure 18: Geographical position of sites of included production cycles (left) and included viral disease outbreaks (right)



Source: (Norwegian Directorate of Fisheries, u.d., Norwegian Veterinary Institute, c, 2017, BarentsWatch, u.d., author creation)

Multifactorial diseases and secondary infections have been proven to be a significant source of the spread and implications of many diseases (Johansen, et al., 2015). Fish that have been through PD outbreaks, for instance, could be more vulnerable to secondary infections (Aukner & Haatuft, 2015). The methodology to identify viral disease outbreaks prioritized PD outbreaks first, ISA outbreaks second, and CMS outbreaks thirdly. This means that when a production cycle experienced multiple outbreaks, the secondary infection only added under the primary infection, and was not allocated its own outbreak figure. The simulation model accommodated both primary and secondary infections.

Analysis of the viral disease outbreak data indicates that secondary infections are indeed a problem for many salmon farmers experiencing viral diseases. For instance, of the 300 PD outbreaks included in the simulations, more than 25% (75 outbreaks) also experienced a CMS outbreak throughout the same production cycle. Table 2 shows the primary outbreaks and secondary infections among the outbreaks in the simulations.

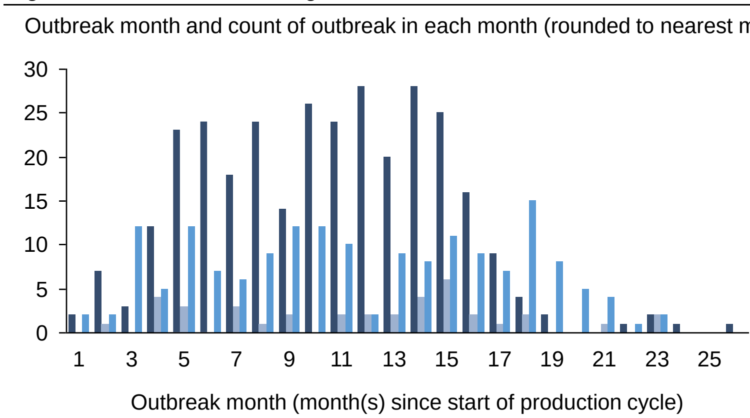
Table 2: Viral disease outbreaks included in simulations by primary and secondary infection (2012-2016)

Secondary infection ►: Primary infection ▼:	PD	ISA	CMS	Total (read: left to right)
PD	240	1	75	316
ISA		33	4	37
CMS			173	252
Production cycles unaffected by viral disease outbreaks of PD, ISA, CMS				857

Source: (Norwegian Veterinary Institute, c , 2017; BarentsWatch, u.d., author creation). Note: Total number of CMS outbreaks is 252. 75 outbreaks are deemed to be secondary infections to PD outbreaks, and 4 outbreaks are demed to be secondary infection to an ISA outbreak. 173 CMS outbreaks is conseqently on a stand-alone basis.

Of the included in outbreaks, the average accumulated time in the production cycle before an outbreak occurred was 10.6, 11.8 and 11.6 months among the included outbreaks of PD, ISA and CMS, respectively. This overall average is affected by the fact that only outbreaks early in the production cycle are included among those detected in 2012, and late in the cycle for outbreaks detected in 2016. For the two years were the included outbreaks provide full coverage (2014, 2015), the average was 10.7, 11.4 and 12.8 months for PD, ISA and CMS, respectively. These results align with published literature, particularly the fact that CMS outbreaks on average occur later in the production cycles than other diseases. There are differences between the S1 and S0 generation in terms of average accumulated time in production cycle before outbreaks occur, likely explained by the implications of higher seawater temperatures during the summer. For the outbreaks detected in 2014 and 2015, the average months before outbreaks for the S1 generation was 11.5, 11.2 and 11.8 months for PD, ISA and CMS, respectively. For outbreaks for the S0 generation, the average time was 9.9, 11.5 and 12.7 for PD, ISA and CMS, respectively.

Figure 19: Overview of timing of included outbreaks of PD, ISA and CMS in the production cycle



	Average outbreak month		
	All generations	S1-generations	S0-generations
PD	10.6	11.5	9.7
ISA	11.8	11.4	12.9
CMS	11.6	10.9	12.5

Source: Author creation

5.3.2.3 Sea lice treatment data

The BarentsWatch data allowed for estimation of the occurrence of mechanical-, medical- and feed sea lice treatments on each site throughout each respective production cycle. The raw data from BarentsWatch highlights the extent of the treatment performed, on the entire or only parts of the site. To account for this, the salmon farmer in the expert panel provided estimates of the portion of a site that would typically be treated if treatment were only performed on parts of a site, an estimate that was inputted as a PERT-distribution. Additionally, the salmon farmer were asked to assess the duration of feeding with sea lice feed, and the increase in feed price per kg of sea lice treatment feed relative to regular grow-out feed. The price increase was similar to figures presented by Iversen et. al. (2015). Based on the inputs from the salmon farmer, it was decided that feeding with sea lice treatment feed typically lasts a full week.

The cost of performing a mechanical treatment on a cage was obtained from Næstvold (2017). The biological production data provided the number of operational cages at each respective point in time.

The cost of each medical tarpaulin bath treatment was estimated in a model based on data from Iversen et. al. (2015). Iversen et. al. (2015) presented the treatment cost associated with different active substances for treating a site with 4.000 tonnes of biomass, and these figures were used to estimate treatment cost on a site equivalent basis for different biomass volumes. The BarentsWatch data provided the active substance used in each respective treatment. Appendix 7 displays the calculations and assumptions of this model.

Finally, each site's release of cleaning fish during each production cycle was obtained from the BarentsWatch data. The price for each cleaning fish was assumed to be equal between the different species of wrasse, not to differ between farmed or wild caught capture, and was obtained from Iversen et. al. (2015).

5.3.2.4 Production cost and sales prices

The following section will discuss each of the production cost categories relevant for the simulations, and discuss the data source for each respective category.

Fixed cost

Salmon aquaculture has a high level of capital intensity, which results in high level of fixed costs (Engle, 2010). The best way to reduce the fixed costs, are as in most other production business to increase the number of produced units to distribute the fixed costs over (Engle, 2010; Anupindi, et al., 2014). Higher production volumes thus result in a lower cost per kilo of produced fish, and therefore better profitability. Weaker distribution of fixed costs is consequently an important implication of viral disease outbreaks. There are several fixed cost components in salmon farming:

Smolt cost

The price per smolt was obtained from Iversen et. al. (2015) for 2012-2014. Kontali Analyse provided the cost per smolt for 2015 and 2016 (Kontali Analyse AS, b, 2017). There was assumed to be no difference in the cost per smolt between Atlantic salmon and rainbow trout, and to not be any regional difference in price per smolt.

Labor cost

Aunsmo et. al. (2010) characterized ordinary labor cost as fixed costs, as the farmers reported that the need for labor "did not decrease with decreased production caused by PD". The cost of ordinary labor was obtained from Kontali Analyse for 2012 to 2016. The provided figures were in NOK/kg of harvested salmon. The figures were converted to a per fish and per correct release year measure by estimating each generations' specific smolt yield based on data from the Norwegian Directorate of Fisheries (Norwegian Directorate of Fisheries, 2016)[5].

Depreciation

Depreciation was deemed a fixed cost as the amount will typically remain unchanged throughout the productive life of an asset. Kontali Analyse provided the deprecation cost estimates for each year between 2012 and 2016 (Kontali Analyse AS, b, 2017). The provided figures were in NOK/kg of harvested salmon. The figures were converted to a per fish and per correct release year measure using the same approach as described above.

Variable costs

Grow-out feed costs

The historical price per kg of feed was obtained from the Norwegian Directorate of Fisheries' profitability study (Norwegian Directorate of Fisheries, 2016), and no county-specific differences were quantified. Sea lice treatment feed costs was explained in section 5.3.2.3.

[5] The smolt yield is a measure of the yield (harvest) per smolt released, and is thus accounting for the mortality of released fish individuals throughout the production cycle. These calculations are shown in Appendix 8.

Insurance costs

The historical cost of insurance, the insurance premium, was obtained from the Norwegian Directorate of Fisheries' profitability survey, measured as NOK/kg of harvested salmon (Norwegian Directorate of Fisheries, 2016). No county-specific difference in the insurance premiums was quantified, even though some insurance providers have previously commented that they have made region specific adjustments to premiums (Furuset, 2016).

Harvesting and well-boat services

The harvesting and wellboat cost was obtained from Kontali Analyse (Kontali Analyse AS, b, 2017). No adjustments were carried out to, for instance, account for differences in distance to the slaughtering facility from the specific site. A separate component was included in model related to the extraordinary cost of harvesting procedures during outbreaks.

Salmon prices and downgrading

The monthly salmon price was obtained from Nasdaq's Salmon Index (Nasdaq, u.d.). The Nasdaq Index quotes the selling price for superior gutted, fresh salmon iced and packed in boxes FCA Oslo (Marine Harvest, 2017), and thus needed to be converted back to a FOB packaging plant sales price for the analysis model. Marine Harvest lists the ten year annual average conversion at 1.45 NOK/kg including SG&A expenses, terminal costs and freight to Oslo (Marine Harvest, 2017). The price data obtained provided price history for each weight class between 1 and 9 kg, in one-kilo increments. Salmon carcasses are categorized in four quality classes: superior, ordinary, production and condemned (Industry Standards for Fish, 1999). Superior fish represent the highest quality, and is the category that salmon price quotes are referencing. The typical share of the biomass in each of the quality classes and the respective reduction in sales price of each class was obtained from Pettersen et. al. (2016). No value is available for the condemned portion of the biomass (Salmonid farmer, a pers. com, 2017). Currently, Norwegian salmon farmers typically use fixed price contracts that can cover up to 50% of their harvest volumes in certain quarters (Marine Harvest, u.d.). Given that there can be a differences between the contract- and spot price in a given period, the price achievement the farmers obtain may be both above and below the respective spot price. However, these differences are assumed to average out over time, and all sales in the simulation model is spot sales with a 100% price achievement.

5.3.3 Implications of disease outbreaks

The following section provides a step-by-step overview of the different components of the framework, and the concrete data and inputs used to estimate each component.

Biological losses

The biological losses were estimated as the difference in economic profit realized for the outbreak affected production cycle and the average economic profit in a corresponding control group of production cycles. The biological losses include differences in mortality, reduced growth post-outbreak, downgrading of saleable biomass, and changes in variable costs. To simplify the simulations, the biological losses were grouped together, and will not be presented separately. All of these estimates were driven by the underlying reported production data. Section 5.4 provides a discussion of the control group utilized in the simulation model.

A challenge with most sources regarding mortality during the production process of salmon is the difficulty to assess the real cause of mortality. Pettersen et. al. (2015) described that "losses from co-infections with HSMI or CMS can influence the reporting of PD specific mortality, leading to overestimated PD mortality". Even though the production data acquired for this thesis did not allow for assigning of mortality to a specific mortality cause, it was decided to not do any specific adjustments to the reported mortality. This was deemed appropriate, as the control group excluded any outbreaks of the viral diseases PD, ISA and CMS. Thus, the control group, assuming similar challenges with sea lice, IPN and HSMI, represented an attainable level of health for a production cycle, without warranting further adjustments. This will not be case if there is an accelerated effect of the implications of IPN and HSMI when an outbreak of these diseases occur as the secondary infection to PD. Section 6.7 further discusses this assumption and implications of it.

Effect on sales and price achievement of disease outbreaks

When farmers are experiencing PD outbreaks, the quality downgrading has been described to be varying based on the average size of the biomass (Pettersen, et al., 2016). Pettersen et. al. (2016) defined different PERT-distributions for fish individuals experiencing PD outbreaks below and above 2.5 kg. These distributions were adapted for used in the simulation model. The monetary price downgrades were equal to downgrades utilized elsewhere in the simulation model. Studies have documented limited differences between SAV2 and SAV3 related to the downgrading of biomass (Jansen a, et al., 2015), and therefore no difference in the realized quality of the biomass at slaughter between the two subtypes of the SAV virus was assumed.

No specific downgrading effect was quantified for fish experiencing ISA outbreaks that had reach satisfactory harvest weight. Two companies working with silage in Norway were contacted, and asked to provide estimates on the salvage value associated with category-3 silage. None of these companies replied to inquiries, and this value was therefore assumed to be zero.

Preventive costs

The preventive costs consisted of two separate components, firstly the preventive costs of vaccination, and, secondly, the costs of implementing biosecurity protocols. Both of these simulations had probability distributions assigned to their simulations.

Not all fish released in Norway is vaccinated against either PD or ISA. Therefore, the cost of vaccination in the simulation model dependent upon the probability of a particular fish being vaccinated. The probability of a fish being vaccinated against PD south of Hustadvika was by the vaccine producers estimated to be 99% (Vaccine producer pers. com., 2017; Vaccine producer, a pers. com., 2017), and was not changed throughout the simulated years. For sites north of Hustadvika, an 18% probability of PD-vaccination was obtained from Jansen et. al. (2015). The probability of PD-vaccination north of Hustadvika has historically been lower due to the lower clinical implications of SAV2 (Vaccine producer pers. com., 2017; Vaccine producer, a pers. com., 2017). No fish that was released north of the border between Nord-Trøndelag and Nordland was assigned a probability for vaccination against PD. The cost of each dose of PD-vaccine was set to 1.8 NOK based on input from the vaccine producers.

The probability of a fish being vaccinated against ISA was approximated from secondary sources and from an interview with a vaccine producer. Only fish released in Troms and Nordland counties were believed to be vaccinated against ISA, and consequently, these two counties were the only two that were assigned a probability of vaccination (Vaccine producer, a pers. com., 2017). The number of fish released in Troms and Nordland was obtained from the NDF (Norwegian Directorate of Fisheries, 2016). The number of vaccine doses including an ISA component was obtained from Pharmaq (Pharmaq, 2017). These two figures were then used to estimate the probability of a site being vaccinated against ISA in Troms and Nordland between 2012 and 2016.

The preventive costs associated with the implementation of biosecurity protocols was obtained from Pettersen et. al. (2015). The same PERT-distribution as utilized by Pettersen et. al. (2015) was copied, after it was decided that the distribution did not overlap with any of model components.

These costs was assumed to be applicable for PD, ISA and CMS, as these protocols “may have effects against several viral diseases” (Pettersen, 2016).

Treatment costs

The treatment cost only included the costs of using clinical PD-feed, meaning that ISA and CMS outbreak did not have quantified treatment costs. The duration of feeding with functional PD-feed was obtained from Pettersen et. al. (2016). Based on published studies, site experiencing an outbreak of SAV3 has a 51.9% probability of using clinical PD-feed during outbreaks, while sites experiencing a marine SAV2 outbreak has a 40.9% probability (Jansen, et al., 2015). To simplify the model, all PD outbreaks north of Hustadvika was assigned the SAV2 probability, while the sites with outbreak south of Hustadvika was assigned the SAV3 probability. The additional price of PD-feed relative to the normal grow-out feed was obtained from the salmon farmer participating in the expert panel, an estimate that aligned with the mark-up presented by Pettersen et. al. (2015).

Extraordinary costs

The participating salmon farmer provided estimates of the extraordinary labor costs associated with viral disease outbreaks and the increased harvest cost per kg of harvested salmon. These estimates were inputted as PERT-distributions. Both figures were higher than figures presented by Aunsmo et. al. (2010) and Pettersen et. al. (2016), but due to limited information regarding the components of those figures, it was decided to utilize the estimates from the salmon farmer. The impact of this should be negligible.

Insurance payout

Based on communication with the insurance companies, the threshold for mortality related claims was set to require above 30% accumulated pen mortality over a 90-day period to warrant a payout. The running pen mortality was estimated from the production data for each pen on each site. One of the insurance companies provided a standard fish insurance value list. The simulation model utilized this value list. The list will change during negotiations of insurance policies between farmer and insurance company, dependent on the farmer’s desires regarding biomass insurance. Even so, the list provides a representative input for estimating the dynamics of insurance policies. When an insurance claim arises, the farmer will receive the per fish value in this value list, adjusted for sales value and a deductible share. The insurance companies said, separately, that the deductible share is typically between 20% and 30% for standard policies. For ISA remediation insurances, the deductible share was reported to always be 40% by both insurers that were interviewed during the preparation of the thesis.

5.3.4 Summary of data used in simulations

The following section provides a tabular overview of the data used in the models' simulation, respective probability distribution when applicable and respective source for each input. Table 3 summarizes the non-outbreak related inputs and data sources. Appendix 9 provides more detail regarding the probability distributions used in the simulations.

Table 3:Overview of non-outbreak production costs inputs

Year-dependent inputs

Model input	2012	2013	2014	2015	2016	Unit	Source
Feed price (grow-out feed)	8.9	9.2	9.7	10.7	11.5	NOK/kg	NDF (2016), Kontali Analyse (2017)
Smolt price per fish	10.1	9.6	10.3	11.1	12.8	NOK/fish	Iversen et. al. (2015), Kontali Analyse (2017)
Ordinary labor cost	1.6	1.6	2.1	2.3	2.8	NOK/kg	Kontali Analyse (2017)
Depreciation cost	1.1	1.2	1.3	1.6	1.6	"	"
Fixed cost per fish (excl. smolt)	13.0	15.0	16.3	17.4	17.4	NOK/fish	Author estimates, Kontali Analyse (2017), Iversen et. al. (2015)
Cleaner fish price per fish	11.4	10.0	11.3	11.3	11.3	"	Iversen et. al. (2015)
Harvest and wellboat cost	2.8	3.2	3.4	3.4	3.7	NOK/kg	Kontali Analyse (2017)
Insurance cost/premium	0.12	0.11	0.10	0.13	0.13	"	NDF (2016)
ISA-vaccinated stock prob.[1]	0%	0%	4%	10%	18%	%	Vaccine producer, NDF (2016), author estimates

1. Only applicable for Troms and Nordland counties.

Non-year dependent inputs

Model input	Parameter	Unit	Source
Additional cost functional lice feed	8.50	NOK/kg	Salmon farmer
Mortality handling cost	1.61	"	Salmon farmer, Pettersen et. al. (2015)
Mechanical sea lice treatments (cage-equivalent)	PERT-distributed (0.09,0.11,0.14)	NOKm	Næstvold (2017)
Medical/bath sea lice treatments (site-equivalent)	See appendix 7	"	Iversen et. al. (2015), author estimates
Maintenance cost per production cycle (site specific)	PERT-distributed (1.9, 2.5, 3.5)	"	Pettersen et. al. (2015), salmon farmers
Superior quality - harvested biomass (%)	94.4%	%	Pettersen et. al. (2016)
Ordinary quality - harvested biomass (%)	2.72%	"	"
Production quality - harvested biomass (%)	2.25%	"	"

Condemned quality - harvested biomass (%)	0.68%	“	“
Ordinary quality reduction in sales price	1.66	NOK/kg	Pettersen et. al. (2015)
Production quality reduction in sales price	8.73	“	“
Duration of functional sea lice feeding period	7	Days	Salmon farmers
Share of site treated in part-site treatments (feed, medical, mechanical)	PERT-distributed (50%, 60%, 70%)	%	“
Deductible share, insurance	PERT-distributed (20%, 25%, 30%)	“	Insurance companies

Table 4 summarizes the outbreak related production costs inputs. These outputs are only applicable for the simulation relating to the production cycles experiencing an outbreak of viral disease.

Table 4: Overview of outbreak related production costs inputs

Model input	Parameter	Unit	Source
Additional cost functional PD-feed	1.88	NOK/kg	Salmon farmers, Pettersen et. al. (2015)
PD-vaccine price	1.80	NOK/dose	Vaccine producers
ISA-vaccine price	1.20	“	“
PD-vaccinated stock SAV-3 (probability)	99.0%	%	Vaccine producers
PD-vaccinated stock SAV-2 (probability)	18.0%	“	Jansen et. al. (2015)
Probability for using functional PD-feed SAV-3	51.9%	“	“
Use of functional PD-feed SAV-2 (probability)	40.9%	“	“
Duration of functional PD-feed feeding period	PERT-distributed (15, 30, 60)	days	Pettersen et. al. (2016)
Extraordinary labor cost to handle outbreaks	(0.5, 1.0, 1.5)	NOK m	“
Preventive costs (vaccination not included)	(0.2, 3.3, 6.4)	“	Pettersen et. al. (2016)
Extraordinary harvest cost of harvesting outbreaks	(1.0, 1.5, 2.0)	NOK/kg	Salmon farmers
ISA-remediation insurance deductible share	40%	%	Insurance companies
ISA-remediation insurance weight cut-off	2.6	kg	“
PD outbreaks <2.5kg	PERT-distributed:		
PD outbreak: Ordinary quality (% of biomass)	(0.66%, 2.66%, 7.13%)	%	Pettersen et. al. (2016)
PD outbreak: Production quality (% of biomass)	(1.41%, 2.21%, 10.93%)	“	“
PD outbreak. Condemned quality (% of biomass)	(0.74%, 1.87%, 6.89%)	“	“
PD outbreak >2.5kg			

PD outbreak: Ordinary quality (% of biomass)	(0.95%, 3.13%, 7.63%)	%	Pettersen et. al. (2016)
PD outbreak: Production quality (% of biomass)	(1.95%, 2.57%, 11.41%)	“	“
PD outbreak: Condemned quality (% of biomass)	(0.72%, 1.99%, 7.12%)	“	“

5.4 Attainable health control group

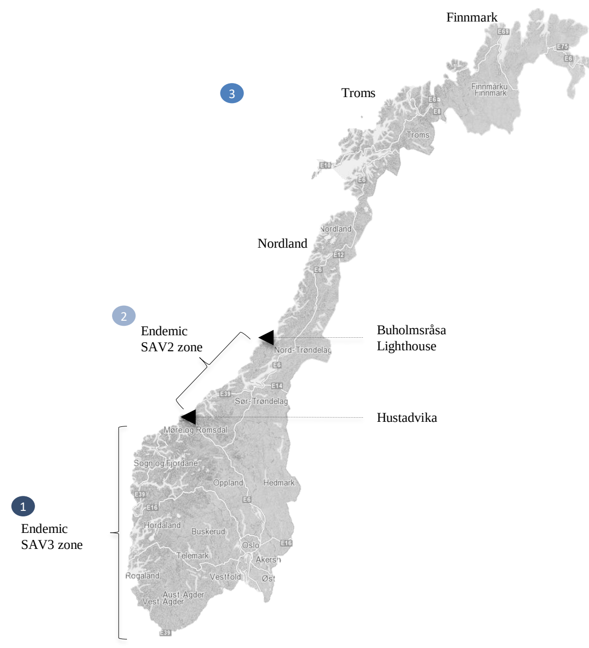
The utilized partial budgeting approach requires a control group consisting of production cycles “unaffected” by disease to quantify the biological losses. This control group needs to represent an “attainable” level of health and not a situation without disease challenges outright (Bennett, 2003). The purpose of the definition of such a control group is to calculate the biological losses portion of the framework, summarized in equation 5. As discussed, the biological losses are the monetary difference between the realized economic profit of a production cycle experiencing a viral disease outbreak, and the economic profit of an “attainable” control group of similar production cycles. Similar ways of developing a control group was, for instance, utilized by Aunsmo et. al. (2010).

It was decided that the control group should only consist of production cycles that was not affected by an outbreak of either PD, ISA or CMS, and to only compromise of sites operating with grow-out licenses. This was done to not introduce any biases in the control group, for instance related to elevated mortality rates, lower growth or forced harvests experienced by some of the production cycles with viral disease outbreaks. Such biases would affect the calculation of biological losses, as the control group should represent an “attainable” production cycle for the site experiencing an outbreak. Including the viral disease outbreaks in the control group would mean that the biological losses would be underestimated. In the simulation model for a particular outbreak, the average economic profit of a representative control group would be estimated based on specific matching characteristics of the site experiencing the outbreak.

Three relevant control group filters were identified with the aim to define each control group. The first filter aimed to control for the potential importance of geography related to cycle productivity. Three regions along the Norwegian coastline was identified to be relevant for the purposes of the control group. The first region was defined to be the endemic SAV-3 zone. This region compromises counties and production areas with similar seawater temperatures, and also production areas that have been awarded similar scores in the first assessment related to the new Norwegian traffic-light system for growth (yellow and red) (The Norwegian Government, b, 2017).

The second region constituted of the production areas between Hustadvika and the county border between Sør- and Nord-Trøndelag, to represent the endemic marine SAV-2 zone. The remaining region consisted of the counties of Nordland, Troms and Finnmark. Particularly in Troms and Finnmark, the seawater temperatures are lower than the rest of the country, which can affect cycle productivity, which motivated the inclusion of this region. A regional approach was preferred over an analysis at a county level, as the dataset was suspected to not provide a satisfactory number of cycles to analyze by county when put in combination with the other filters.

Figure 20: Map overview of regions (1-3) defined to test control group specification



Source: (BarentsWatch, u.d., author creation)

Secondly, the MAB limit of sites was included as a filter to control for identifiable differences in site size and production. A correlation between with the generation of output and input use, and the size of a site was expected. The MAB limit of the different sites were organized into three different categories, based on an analysis of Norwegian sites' MAB limits. The criterion was defined as: sites with MAB limit below 2.800 tonnes, sites with MAB limit equal to 2.800 and up to 3.800 tonnes, and sites with MAB limit equal to and above 3.800 tonnes. Appendix 10 provides an overview of Norwegian farming sites' MAB limit, and the analysis.

Lastly, cohort generations was included as a filter to control for differences between generations. Different generations can have differences in productivity based on factors they experience throughout their life cycle, for instance varying seawater temperatures. The S12016 and S02016 generations were excluded from this particular exercise, to focus the analysis on completed production cycles only. Appendix 11 provides a timeline overview of different fish generations in Norway, including general stocking and harvesting periods, highlighting that these two generations were not completed before YE 2016.

The respective control group for each production cycle experiencing a viral disease outbreak would therefore consist of sites that matches all or some of the criteria outlined above, e.g. same MAB limit, same region and/or same fish generation cohort.

Given that it was unknown which filters would be relevant to include, it was decided to develop a regression model to test the filters. A regression model was developed in STATA to decide on which filters that would statistically significant to filter the control groups based on. The regression model was solely developed to test different specifications of the control group, and not for any estimation purposes in the simulation model. Through analysis of the 2063 production cycles that were identified in the production data, 1206 of these production cycles were removed due to not being completed before YE 2016, had experienced viral disease outbreaks of PD, ISA or CMS, had missing MAB limit data or operated with research-, exhibition- or broodstock licenses. The rational for only including grow-out licenses is that neither of the other license categories necessarily will follow regular production cycles. A research site might test different scientific concepts and ideas in different pens, while broodstock licenses will deliberately allow the fish to mature before stripping eggs. Ultimately, the dataset for the control group of production cycles with attainable health and no outbreaks of the relevant viral diseases consisted of 857 production cycles.

The dependent variable in the regression model was defined to be feed consumption per production cycle per farming site, to work as a proxy for cost, relative size of the site and fish growth, obtainable purely from the production data. It was decided that this was more appropriate than analyzing the estimated economic profit of each production cycle, as this estimate would be affected by, for instance, changing salmon prices within a generations' harvesting period. A dummy variable was assigned to n-1 parameters, to avoid the model having perfect multicollinearity (Stock & Watson, 2015).

Four regression specifications were defined to test each of the filters outlined in the section above. Table 5 presents an overview of the different regression model specifications.

Table 5: Overview of regression model specifications for testing control group specification

Specification	Specification description
Specification 1	$Feed_{cycle} = SAV3 \text{ x } D_1 + SAV2 \text{ x } D_2 + B_0$
Specification 2	$Feed_{cycle} = SAV3 \text{ x } D_1 + SAV2 \text{ x } D_2 + MAB_{<2700} \text{ x } D_1 + MAB_{2700\text{-}3800} \text{ x } D_2 + B_0$
Specification 3	$Feed_{cycle} = Generation_1 \text{ x } D_1 + \ldots + Generation_6 \text{ x } D_6 + SAV3 \text{ x } D_7 + SAV2 \text{ x } D_8 + MAB_{<2700} \text{ x } D_9 + MAB_{2700\text{-}3800} \text{ x } D_{10} + B_0$
Specification 4	$Feed_{cycle} = Generation_1 \text{ x } D_1 + \ldots + Generation_6 \text{ x } D_6 + MAB_{<2700} \text{ x } D_7 + MAB_{2700\text{-}3800} \text{ x } D_8 + B_0$

Where $Feed_{cycle}$ is the total feed consumption of a particular production cycle at a particular site, Generation is the respective fish generation and SAV3 and SAV2 is the respective Norwegian region and $MAB_{<2700}$ and $MAB_{2700\text{-}3800}$ is the MAB limit category of each site

The regression analysis presented in Table 6 shows that specification three and four obtain a similar adjusted-R^2. The signs and the magnitudes of the terms are also very similar between the two specifications. Both of the MAB limit terms are statistically significantly different from the largest MAB-category, with a p-value below 0.1%. Additionally, some of the time (generation) terms are statistically significantly different from the excluded generation in both specification three and four. One can observe limited changes for the terms for MAB limit by adding the time-dependent variable for generations, indicating that the importance of MAB limit in itself does not vary much over time. Limited explanatory power seems to stem from the region of the site, as these terms are neither statistically significant in specification 2, nor specification 3. Overall, this warrants the conclusion that control groups filtered by MAB limit and generation is appropriate. To conclude, these two filters will therefore be utilized in the simulation model. Section 6.7.4 presents and discuss the consequences for the results of the simulations of including or excluding regions in the construction of control groups.

Table 6: Overview of regression output for testing control group specification

	Feed consumption per production cycle			
	Specification 1	Specification 2	Specification 3	Specification 4
SAV3 endemic zone	-1089.6***	-213.3	-141.3	
	(188.7)	(164.6)	(163.3)	
SAV2 endemic zone	190.9	6.425	30.17	
	(233.8)	(196.0)	(194.3)	
MAB limit <2700		-3546.6***	-3560.5***	-3614.6***
		(183.5)	(181.6)	(172.9)
MAB limit 2700-3800		-1722.7***	-1730.5***	-1748.3***
		(177.9)	(175.9)	(174.3)
S12012			58.38	55.47
			(232.9)	(232.5)
S02012			-199.5	-208.6
			(256.5)	(256.0)
S12013			812.5***	815.0***
			(244.9)	(244.0)
S02013			527.7*	522.3*
			(258.9)	(258.4)
S12014			791.9**	807.3***
			(244.8)	(244.1)
S02014			439.1	449.9
			(263.3)	(262.9)
_cons	4073.2***	5652.3***	5302.3***	5281.7***
	(124.0)	(146.7)	(205.5)	(189.8)
N	857	857	857	857
adj. R^2	0.045	0.335	0.352	0.353

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5.5 Model assumptions

The following section contains an overview of the key assumptions and simplifications, not explained elsewhere, utilized in the simulation model.

5.5.1 Weight of dead fish

Pre-, during and after an outbreak, some fish may experience lower growth than the average of the impacted fish (Aukner & Haatuft, 2015). This can be because, for instance, the site has experienced a prior infection or that some of the fish have become “loser-fish”. Consequently, some of the fish that dies during the production cycle may have a lower weight than the average fish in that pen (Pettersen, et al., 2015). In the simulations in this project, all fish individuals in the pens were assumed to have the same weight throughout the production process, and thus no variations in the weight of each fish that dies have been included.

5.5.2 Movement of fish

The production data received from NDF did not provide sufficient information regarding movement of fish to fully be incorporated in the model. The dataset only provided the total volume of fish, in kg, moved out of a particular site, and the number of fish released into another site. It was not feasible with the available data to match these figures together. In order for the model to not double-count the cost per fish being released into a particular farming site, only the net fish release during the first seven months of each generation was counted as the smolt release of that particular site's production cycle. This has the implication that the cost per fish of moved fish was allocated to the production cycle on the site the fish was originally released at. Consequently, the variable costs of moved fish up until the transfer was also allocated to the original production cycle.

A company internal pricing model for fish was developed, to control and account for movement of fish. It was assumed that the fish that was released into, and moved out of a site had the same weight as the average weight on the site at the time of movement. This assumption allowed for the estimation of the number of fish sold, and the volume of fish released. It was assumed that no margin was obtained on internal sales of biomass. To have a universal pricing principle for fish at different weights, the fish's value was estimated using the insurance value list. This simplification was deemed to be appropriate, given the inherent complexities of allocating and, particularly, matching the incurred working capital of specific fish individuals. Additionally, production cycles that launched fish over 1 kg was deemed to launching fish that was moved from another seawater site. This assumption was added to make sure not to underestimate the cost of smolt, as the smolt price included in the model only was applicable for smolts around 100 grams. Release of fish below 1 kg was assumed to be purchased as smolt. It is believed that this adjustment calculation cancels out some of the implications presented in the preceding paragraphs. Of the total production cycles that were included in the control group, 30% of these had seen outgoing movement of fish. Even so, the average tonnage of moved fish was 240 tonnes, indicating that the implications for the simulation results should be negligible.

5.5.3 Differences between Atlantic salmon and Rainbow trout

There are assumed to be no differences in the inputs between Atlantic salmon and Rainbow trout. Rainbow trout have over the latter part of the analysis period experienced a lower sales price than Atlantic salmon (Sjømat Norge, n.d.), primarily following the Russian import ban that was imposed in August 2014 (Berge, a, 2017). The simulation model only implements Atlantic salmon price quotes. Even so, Rainbow trout typically develop less clinical disease than Atlantic salmon for PD and ISA, and thus features more seldom in the outbreak statistics. Rainbow trout account for only 8% of the overall entries in the production data. This simplification is therefore believed to have only minor impacts on the results of the simulations.

5.5.4 Generation control group assumptions

The production data was only made available by NDF to this project up until 31.12.2016. This has the implication that the production cycles in the control group of the S12016 and S02016 generations had not been completed within the dataset. The project aspired to include all of the outbreaks detected in 2016, which had completed production cycles, in the simulation model. Therefore, it was decided that the production cycles in the control group for the S12016 and S02016 generations should consist of the last completed cycle of the same cohort, namely the S12015 and S02015 generations, with cost inputs updated to 2016 data, and the salmon price moved ahead one entire year for these generations. This will therefore return different economic profit estimates than for the previous year. This assumption is deemed a conservative assumption, given biological improvements in 2017. The generational biology in Norway in recent years have been improving in the salmon's first year at sea, but those gains have been overshadowed by what has been described as "close to disastrous second years at sea" (Kontali Analyse AS, a, 2017). However, 2017 seem to have improved compared to recent years. Particularly the S0 generation of the 2016-G in Norway has performed significantly better biologically than the corresponding 2015 cohort, with the total biomass of the 2016-G being 4-6% higher than the 2015-G at the corresponding time in the production cycle throughout 2017 (Kontali Analyse AS, a, 2017). Overall, this indicates that the biology has improved year-over-year in 2017, which imply that the generational assumption is conservative.

5.5.5 Viral disease outbreaks effect on salmon prices

No adjustments were made to the salmon prices obtained from Nasdaq. This means that the study implicitly assumes that viral diseases do not have any effect on the salmon prices, i.e., that salmon prices would not be higher if one excluded viral disease outbreaks from the statistics. This is believed to be accurate, as neither of the viral diseases directly makes the fish unsaleable. The fish experiencing viral disease outbreaks might have a higher share of quality downgrades, for instance, but there are no indication that the sales value for the superior portion of the biomass should be any lower for volumes affected by viral diseases. Some countries, such as China, New Zealand and

Australia have bans on the import of ISA-infected fish (NFSA pers. com., 2017). However, the impact of these bans on the salmon price is believed to be minor. Australia and New Zealand are self-supplied on farmed salmon (Kontali Analyse AS, 2017), and historically trade-bans with China is likely to be much more important driver for the salmon price and demand in this region. The study did not identify similar bans or related challenges in the sale of fish infected with PD or CMS.

6. Analysis and results

The simulation model was constructed in Microsoft Excel, and the probability distribution simulations were run through the add-in Oracle Crystal Ball. As discussed in section 5.1, the simulation model utilized probability distributions to simulate certain model inputs. The simulations used Latin hypercube sampling with a sample size of 500 bins and 400 iterations in the trails for each probability distribution. Appendix 12 provides a full, sanitized, overview of all of the simulated outbreaks' mean simulated values. As mentioned previously, the list of outbreaks is only complete for 2014 and 2015, as only concluded production cycles could be included in the simulations. Therefore, analysis of aggregated figures is only valid for outbreaks detected in 2014 and 2015. The estimates presented in the following section does not take into account the potential the farmers have to move unused MAB capacity to other farming sites following an outbreak, applicable mainly to PD outside of the endemic areas. The presented estimates are therefore the gross losses stemming from a viral disease outbreak.

Chapter 6 will first present the national results for each disease, including the cost to the value chain and net costs experienced by farmers. The first section will further discuss the key considerations related to the size of each outbreak, and the explain differences over time. The second section will present the results on a regional basis, with granularity down to each production area. Further, the thesis will discuss the breakdown of the direct costs by each of the cost categories. Section 6.4 discusses the implications of secondary infections. Section 6.5 presents an analysis of the biological production data that analyzes differences in key productivity measures between production cycles affected by viral diseases and the control group. Section 6.6 analyzes the obtained results in light of previously published studies assessing economic losses with PD, ISA and CMS. Finally, the chapter discusses the limitations and sources of error present in the study.

Some of the results of the in the simulations are displayed as negative. This indicates that sites' economic profit is higher than the economic profit of the comparable control group, consequently leading to "positive" biological losses. A site with a MAB limit in the upper parts of each MAB category would be expected to, for instance, generate a higher economic profit than a smaller site in the same category. To ensure a sufficient sample size in each of the control groups, this is not possible to avoid. Even so, the variation in implications for sites experiencing outbreaks should indicate that some outbreaks would not see an increase in direct costs. This can be the case for a site experiencing a viral disease outbreak late in a productive production cycle, for instance.

6.1 National results

The national results are reported both on a value chain and on a net cost to salmon farmer basis. The difference between the two figures is the insurance payout. The difference between the two estimates for PD and CMS outbreaks are minor, but are higher for ISA outbreaks given the remediation insurance policies. The focus of the analysis will be on the losses to the salmon farmers as insurance policies are a natural part of salmon farming operations, and potentially can mitigate potions of the loss stemming from disease.

The total direct costs to the value chain of the included PD, ISA and CMS outbreaks from 2012 to 2016, presented as mean of simulated figures, was 8340 NOKm, 1703 NOKm and 1452 NOKm, respectively. The estimated total direct costs to the value chain of the included outbreaks, by year of disease detection, is presented in the table 7.

Table 7: Total direct costs to the value chain (NOKm) and Share of costs to farmers (%) of included PD, ISA and CMS outbreaks (NOKm), by year of disease detection.

	PD					ISA					CMS				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
5th Percentile															
Costs to value chain (NOKm)	105	1553	2374	2413	1276		73	280	935	311	410	189	-55	651	-156
Share of costs to farmers (%)	*100*	*98*	*98*	*98*	*100*		*80*	*91*	*93*	*89*	*99*	*96*	*81*	*100*	*103*
50th Percentile															
Costs to value chain (NOKm)	112	1699	2589	2596	1344		92	306	969	337	449	287	68	751	-103
Share of costs to farmers (%)	*100*	*98*	*98*	*98*	*100*		*87*	*91*	*93*	*90*	*99*	*98*	*79*	*99*	*104*
95th Percentile															
Costs to value chain (NOKm)	121	1912	2914	2826	1434		111	330	1001	362	487	383	233	852	-52
Share of costs to farmers (%)	*100*	*98*	*99*	*98*	*100*		*87*	*92*	*94*	*91*	*99*	*98*	*94*	*100*	*107*

Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

The remaining sections of the analysis will be analyzed on a net-costs-to-farmer basis. The mean of the simulations of the included outbreaks yielded an aggregated estimate of net direct costs associated with from 2012 to 2016 of 8217 NOKm for PD, 1566 NOKm for ISA and 1420 NOKm for CMS. The 5th percentile of simulated values was 7603 NOKm, 1465 NOKm and 1008 NOKm for PD, ISA and CMS, respectively, and the 95th percentile of simulated values aggregated to 9079 NOKm, 1666 NOKm and 1870 NOKm, for PD, ISA and CMS, respectively. Table 7 displays the direct costs to the salmon farmers of the included outbreaks, by year of disease detection and the simulated values for the 5th, 50th and 95th percentile.

As covered previously, the model only has full coverage for 2014 and 2015. In 2014, the mean of simulated values for direct costs to farmers was 2548, 279 and 54 NOKm for PD, ISA and CMS, respectively. In 2015, the corresponding figures was 2547, 905 and 747 NOKm for PD, ISA and CMS. The simulated figures indicate that the outbreaks of PD, ISA and CMS likely cost Norwegian salmon farmers more than four NOKb per year on an aggregated basis, based on the estimates for 2015. Given Norway's harvest volumes of Atlantic salmon and Big trout in 2015, the 2015 mean-of-simulated values estimate is equivalent to direct costs of 3.76 NOK/kg HOG. The estimates for PD indicate the disease cost farmers approximately 2.2 NOK/kg of harvested salmon each year. The implication of ISA and CMS varies, but seemingly adds direct costs up to 0.8 NOK/kg and 0.7 NOK/kg in certain years, respectively. In comparison, Norwegian farmers released labor costs of harvested fish of approximately 2.3 NOK/kg in 2016, and had smolt costs of close to 3.0 NOK/kg. Table 8 presents the estimated direct costs as a NOK/kg of harvested salmonids in 2014 and 2015, as these are the two years with full coverage of outbreaks.

Table 8: Total direct costs to farmers (NOK/kg of harvested salmonids) of included PD, ISA and CMS outbreaks (NOKm), by year of disease detection

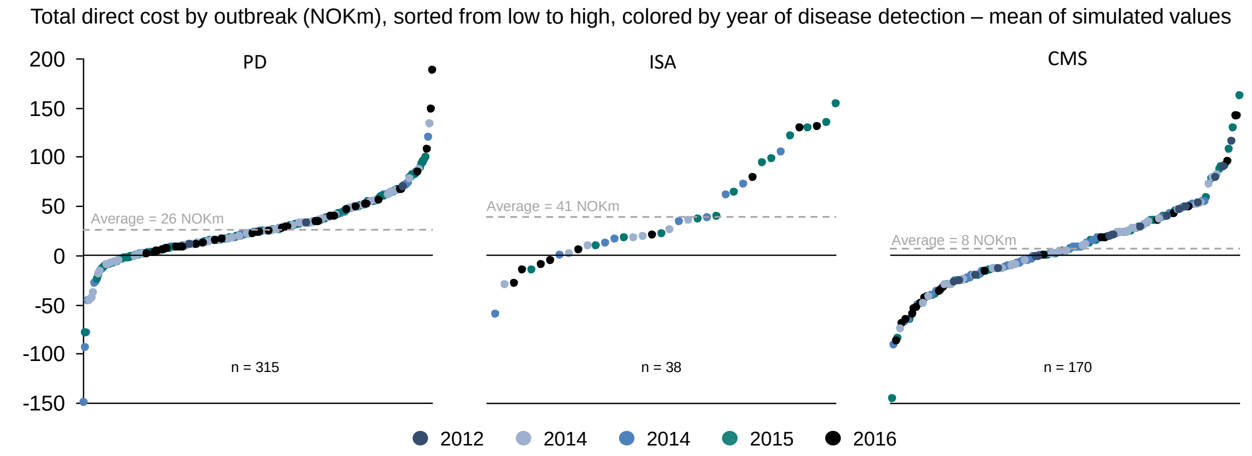
	PD		ISA		CMS	
	2014	2015	2014	2015	2014	2015
5th Percentile	2.02	2.01	0.22	0.74	-0.04	0.55
50th Percentile	2.21	2.16	0.24	0.77	0.05	0.63
95th Percentile	2.51	2.35	0.26	0.80	0.19	0.72

Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

The losses are disperse among farming groups. Twenty-two farming groups were identified to have incurred losses above 100 NOKm from the three viral diseases accumulated. The average accumulated direct costs for each of the seventy-five farming groups that had outbreaks included, amounted to 138 NOKm. Six farming groups had incurred estimated losses of at least 500 NOKm.

The simulated total direct costs for each outbreak vary significantly. As displayed in Figure 21, the estimates range from direct costs at close to 200 NOKm for some respective production cycles, to "positive" direct costs at close to 150 NOKm. The majority of the included outbreaks' simulated mean values are net losses, however. Of the included outbreaks, 49 (15%), 8 (21%) and 75 (44%) outbreaks for PD, ISA and CMS respectively, had "positive" total direct costs compared to the control group, and including the four other cost categories. The higher portion of CMS outbreaks that are "positive" indicate that the implications of CMS outbreaks are varying, which support previously mentioned literature that describes that the disease can lead to mortality levels that vary from "negligible to 100%" (Timmerhaus, 2011). These results indicate that farmers that experience CMS outbreaks face uncertainties regarding the implication the disease will have.

Figure 21: Overview of total direct costs of all included outbreaks

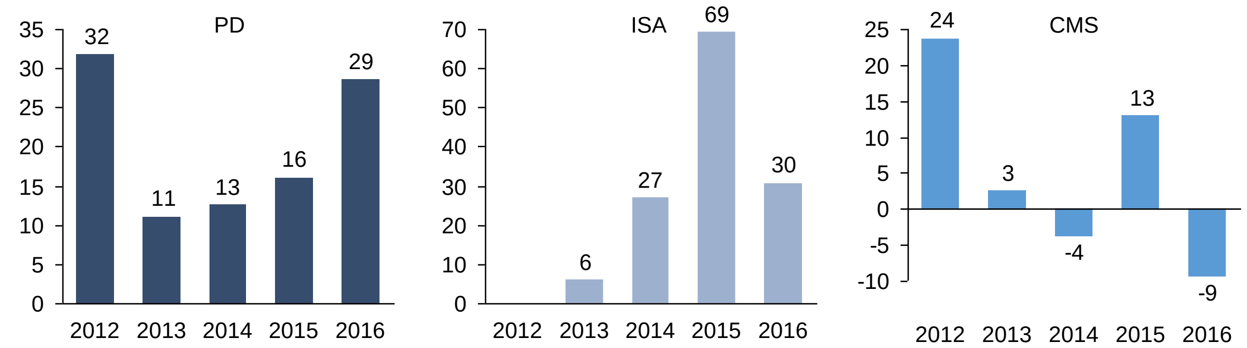


Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

Viral diseases can typically affect outputted volumes from each production cycle, and consequently, a key driver for losses is the salmon price. Theoretically, the higher salmon prices seen in recent years will therefore increase the implications of mortalities and weaker yield performance in production cycles. This theory is supported by the simulated figures, as displayed in Figure 22. The simulations show that the average monetary biological losses associated with each of the viral diseases have increased in recent years, particularly for PD. The biological losses for both PD and CMS among the outbreaks detected in 2016 are not complete, as the majority of these outbreaks affected generations that had not completed their production before year-end 2016.

Figure 22: Average biological losses of included outbreaks by year of disease detection

Average total biological losses (NOKm) by year of disease detection – mean of simulated values

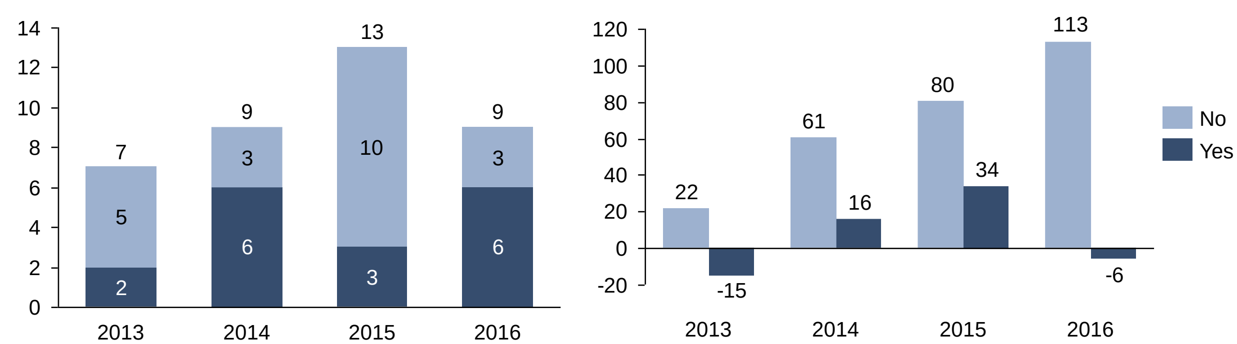


Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

Table 7 displays that the losses associated with ISA have varied in recent years. The analysis indicate that the lower simulated values in 2016 are likely related to a higher share of outbreaks being detected when the fish were above 2.6 kg. As displayed in Figure 23, two-thirds of the included ISA outbreaks that detected in 2016 happened when the fish was above 2.6 kg. Consequently, the majority of the outbreaks in 2016 had lower direct costs than other years given that the fish was of a harvestable size, rather than destructed upon outbreak. Meanwhile, the average direct costs associated with outbreaks below 2.6 kg peaked in 2016, indicating that the mix between smaller and bigger sized fish affected by outbreak will be a key determinant for the ISA-related losses going forward. This specific analysis is only applicable to ISA, as the outbreaks of the other diseases are unaffected in terms of mandated actions by the biomass weight at the outbreak of disease, unless it concerns a specific SAV-subtype outside of the endemic area.

Figure 23: Number of ISA outbreaks above 2.6 kg, and average total direct costs per outbreak by year of disease detection above and below 2.6 kg

Number of ISA outbreaks included in simulation above 2.6 kg (Yes = above), and average total direct cost per ISA-outbreak by year of disease detection (NOKm) – mean of simulated figures

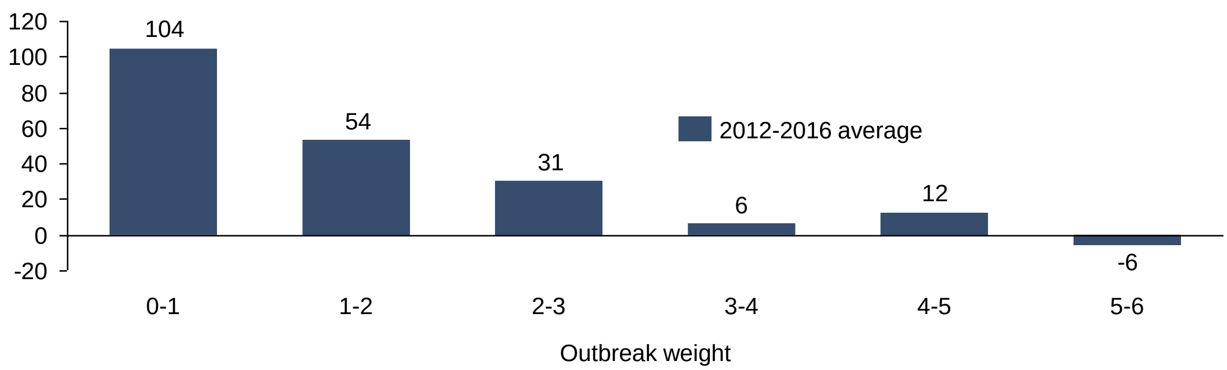


Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

Based on the mandated implications for farmers experiencing ISA outbreaks, it was expected that the direct costs of a particular ISA outbreak is higher the earlier in the production cycles they occur. The simulations show that fish that experience ISA outbreaks before having reached harvestable size, on average, lead to higher total direct costs for the farmer. A lower fish weight at the time of outbreak means the farmer forgoes a proportionally higher volume of harvest towards the end of the production cycle, increasing the losses. These results also shows that even though ISA-remediation insurance is available for smaller fish sizes, the high deductible share and the potential for insurance values to be lower than incurred stocking costs, lead to higher losses the earlier in the production cycle an ISA outbreak occur.

Figure 24: Direct costs per ISA outbreak in different weight classes

Average (2012 – 2016) total net direct costs per ISA-outbreaks in different weight classes (NOKm) – mean of simulated values



Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

6.2 Regional results

From 2017, the Norwegian coastline will be divided into thirteen different production regions for aquaculture, as a part of the implementation of the new growth regime. The regional results will therefore be described on a production area basis to be relevant for the industry's adaption to the new regions. Farming companies, including Marine Harvest, has announced that they are streamlining their Norwegian business to better adapt to the regulatory changes (Intrafish.no, 2017). Appendix 1 provides an overview of the Norwegian production areas. Table 9 provides an overview of the estimated direct costs in each of the production areas, by year of disease detection.

Table 9: Regional breakdown of total direct costs, by year of disease detection and production area (NOKm)

	PD					ISA					CMS				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Øst-Finnmark												27			
Vest-Finnmark	69	110							129		164	-55	164	489	-84
Kvaløya til Loppa							10	33				3		97	17
Andøya til Senja								61	288				-22	-59	124
Vestfjorden og Vesterålen							63	244	372		39		21	2	
Helgeland til Bodø							5	-60		163	19		-16		
Nord-Trøndelag med Bindal			271	55	336						19	158	-127		148
Nordmøre og Sør-Trøndelag	43	693	377	208	74				98	142	219	189	-18	97	-22
Stadt til Hustadvika		140	364	120	233							-66	-109	-49	-87
Nordhordland til Stadt		116	500	544	158						-14	24	-45	189	-91
Karmøy til Sotra		562	658	1096	540				18			18	116	23	-44
Ryfylket		49	379	526								8	71	13	-69
Svenskegrensen til Jæren												-26	20	-55	

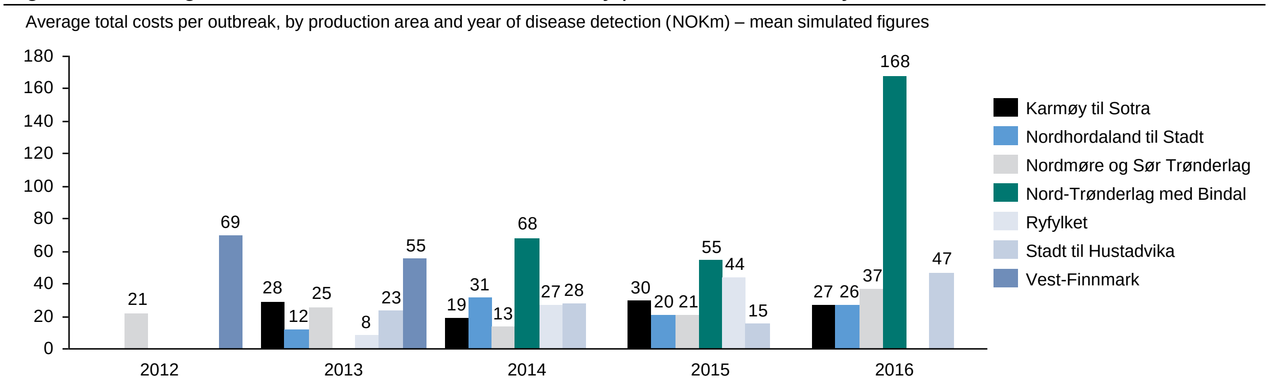
Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit.

For PD, the regional results of the simulations align with expectations. The majority of the PD outbreaks in Norway occur within the endemic SAV-3 zone, and the direct costs should therefore be higher in this area. The simulation shows that the production areas of Karmøy til Sotra, Nordhordaland til Stadt and Ryfylket, all within the counties of Rogaland, Hordaland and Sogn og Fjordane have experienced the highest losses associated with the disease in recent years. These three production areas accounted for 62% of total direct costs among the simulated PD outbreaks, equivalent to 5127 NOKm.

The "stamping-out" policy for farmers in Nord-Trøndelag have meant that it would be expected that direct costs for PD outbreaks in this area was higher than elsewhere. Seven PD outbreaks north of Buholmsråsa was included in the simulation model, accounting for 2 % of all included PD outbreaks. The total combined monetary direct costs incurred by these outbreaks, in the mean of the simulations, was 661 NOKm, or 8% of the total monetary PD-costs nationwide. These simulation results illustrates the implications the "stamping-out" policy has had in Nord-Trøndelag. Further, the size of this figure, from the local farmer's perspective, underlines the importance of altering the PD-regulation in this region, even though "stamping out" will likely continue to be a measure. Figure 25 shows the average total direct costs in the mean of simulated values per outbreak in each production area, and clearly shows that the production area of Nord-Trøndelag med Bindal experience higher losses associated with PD outbreaks.

Note that this estimate does not take into account the overall implication for the farming group experiencing the outbreak outside of the endemic area, as it can be mitigated and reduced for instance by moving fish into the endemic area following an outbreak. Of the six PD outbreaks analyzed in the production area of Nord-Trøndelag med Bindal, four of these outbreaks moved the majority of the biomass to another farming site. Two of the outbreaks harvested the fish, likely because the average fish weight was above 3 kg at the time of disease detection. Moving fish to another farming site can weaken the overall utilization of the company's MAB-capacity. If the company does not have any empty sites the fish can be moved to, moving fish to a site were other biomass is already stocked will lower the MAB limit of that site. This will happen as increasing the number of stocked fish will mean that the farmer reaches his MAB limit at a lower weight than planned, forcing him to harvest earlier than planned to comply with the limit. However, most of the farming groups in Nord-Trøndelag are companies with multiple sites, and the movement of fish can therefore be viewed as an indication that company is able to facilitate for the volumes at another site, without too much of an impact of the MAB-portfolio. In general, a farming license in Norway can currently use up to four sites (Marine Harvest, 2017), which illustrates the flexibility the companies have to handle fish movement.

Figure 25: Average total direct costs for PD outbreaks, by production area and year of disease detection



Source: Study simulations

ISA outbreaks are not as geographically dependent as there historically has not been any differences in regulations based on where the outbreak occurred. Therefore, no specific differences in the losses associated with outbreaks of ISA based on geography could be identified, other than related to where an elevated incidence rate, and fish size related factors could be observed.

The direct costs associated with CMS outbreaks was also related to the incidence rate in specific counties. Given that CMS is unlisted, and no specific eradication measures are mandated when an outbreak occur, this is to be expected.

6.3 Costs by category

The simulation model consisted of five cost categories. The following section will discuss and show the results related to each model component. Table 10 shows the breakdown of the estimates direct costs into each of the five cost categories.

Table 10: Simulated total direct costs associated with PD, ISA and CMS outbreaks 2012 – 2016, by year of disease detection and cost category – mean of simulated values (NOKm)

	PD					ISA					CMS				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Biological losses	95	793	1385	1527	1003		43	242	899	274	379	104	-189	546	-218
Cost of treatment	1	111	127	173	56		0	0	0	0	0	0	0	0	0
Cost of prevention	11	386	515	453	152		23	30	43	30	53	132	161	138	76
Other extraordinary costs	5	409	563	443	133		26	34	27	34	18	51	95	67	39
Insurance payout		31	41	49	2		14	27	64	32	3	6	14	4	4
Total direct costs	112	1668	2548	2547	1342		78	279	905	304	446	280	54	747	-107

Source: Author creation

Table 11 displays the development in average direct costs for each of the disease, by year of disease detection, divided into each simulated cost category. As mentioned above, the higher salmon prices in recent years is likely a driver for increasing total direct costs, affecting the figure for biological losses.

Table 11: Simulated average direct costs associated with PD, ISA and CMS outbreaks 2012-2016, by year of disease detection – mean of simulated values (NOKm)

	PD					ISA					CMS				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Biological losses	31.7	11.0	12.6	16.1	28.6		6.2	26.9	69.2	30.4	23.7	2.6	-3.9	13.0	-9.5
Cost of treatment	0.3	1.5	1.2	1.8	1.6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cost of prevention	3.6	5.3	4.7	4.8	4.3		3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Other extraordinary costs	1.8	5.6	5.1	4.7	3.8		3.7	3.8	2.1	3.8	1.1	1.3	1.9	1.6	1.7
Insurance payout	0.0	0.4	0.4	0.5	0.1		2.0	3.0	4.9	3.6	0.2	0.2	0.3	0.1	0.2
Total direct costs	37.4	23.2	23.2	26.8	38.3		11.2	31.0	69.6	33.8	27.9	7.0	1.1	17.8	-4.7

Source: Author creation

The simulations show that both the cost of prevention and other extraordinary costs can be significant for farmers that experience PD outbreaks.

The ISA outbreaks had a proportionally higher share of losses stemming from biological losses than PD. The fact that ISA outbreaks below harvestable weight renders the biomass unsaleable is an important difference that explain the difference to PD outbreaks. The insurance payout is also proportionally higher for ISA outbreaks than for PD and CMS outbreaks, driven by the ISA-remediation insurance policies.

CMS outbreaks on average had lower overall direct costs, but utilized the same prevention cost PERT-distribution as the PD and ISA simulations, explaining the proportionally higher costs related to prevention. Table 12 displays an overview of the proportion of each cost category for each of the three analyzed diseases.

Table 12: Simulated portion of economic costs in each category - mean values (5th, 50th, 95th percentiles) 2012-16 (%)

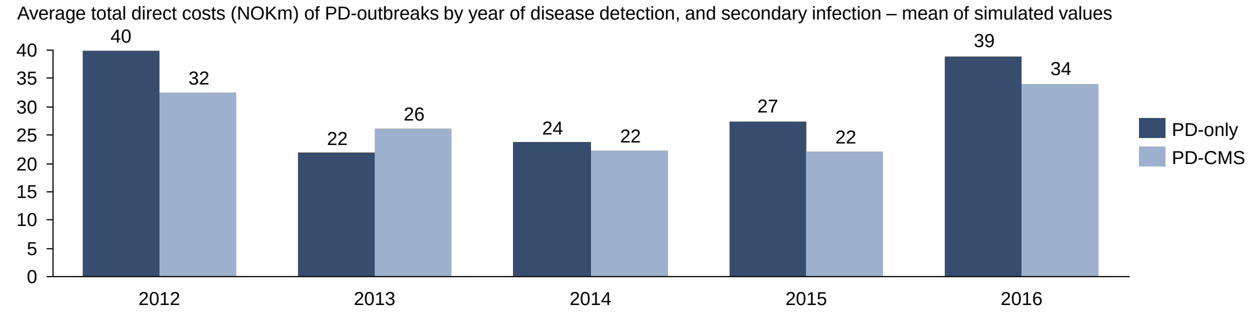
	PD	ISA	CMS
Biological losses	58	93	44
Cost of treatment	6	0	0
Cost of prevention	18	8	39
Other extraordinary costs	19	8	19
Insurance payout	-1	-9	-2
Total direct costs	100	100	100

Source: Author creation

6.4 Implications of secondary infections

As previously mentioned, secondary infections are described to be a problem for many farmers that experience an outbreak of, particularly, HSMI, CMS and PD. The study find limited indications that secondary infections lead to any particular heightened losses for farmers. As displayed in Figure 26, the average direct costs per outbreak has over the last years been similar between a group consisting of PD with no secondary infection (n=225) and a group of PD outbreaks that also contracted CMS during the production cycle (n=75). However, these results are not to be expected and might indicate certain issues with control group for CMS outbreaks. Analysis of the differences between the groups explains part of the results. For the outbreaks detected in 2012, 2013, 2015 and 2016, the average time before the PD outbreak occurred was later for the production cycles with secondary infections, at 4.5, 0.8, 0.7 and 1.26 months later, respectively. This implies that there is a shorter time for the biological implications to materialize, and consequently the total direct costs can reasonably be lower for the group of secondary infections. These implications are not researched or analyzed further.

Figure 26: Average total direct costs for PD outbreaks, by PD infection only and PD with CMS secondary infection



Source: Author creation

The overall implications of production cycles experiencing a CMS outbreak, both as the primary and secondary infection have combined direct costs of 723 NOKm and 1325 NOKm in 2014 and 2015, respectively. This figure differs from those presented earlier in this chapter, as CMS infections were given the lowest priority when defining each outbreak. For each of these years, the secondary infections with PD accounted for 82% and 34% in 2014 and 2015, respectively.

6.5 Biological implications of outbreaks

In addition to the economic analysis, the obtained production data facilitates for the analysis of biological differences between outbreak and non-outbreak production cycles. The results show an identifiable difference between the production cycles experiencing outbreaks and those that do not.

For PD, the analysis show that production cycles that are affected by PD have longer production cycles than a control group without the three viral diseases. This is an indication that compensating for the biological implications of outbreaks, e.g. lower growth post-outbreak, by extending the production cycles is indeed a common way to mitigate the challenges of the disease. On average, the stocking period is 2.48 months longer for production cycles with PD outbreaks than for the control group. The analysis also shows that PD outbreaks have higher bFCR and eFCRs than the control group. This aligns with findings of other studies into the biological implications of PD outbreaks. The eFCR for a production cycle experiencing a PD outbreak is on average 0.182 times higher than for the control group, which for a site harvesting 4000 tonnes of fish throughout a production cycle equates to 760 tonnes more feed, or increased feed costs of approximately 8 NOKm for a given production cycle. The smolt yield is also seemingly affected by PD outbreaks, but given that a longer production cycle can be observed for PD outbreaks, this is likely driven by the "stamping-out" regime, and not solely biology. All of the terms mentioned above are statistically significantly different from the control group at the lowest significance level. Lastly, a minor increase in the overall cycle mortality rate is observed among PD outbreaks, statistically significant at a 5% significance level.

Among the ISA outbreaks, it is also clear that the biology is affected by outbreaks. Particularly the smolt yield, on average almost 1 kg below the control group, shows the implications of harvesting fish lower than optimal harvest weight. The mortality rate of ISA outbreaks in the simulations are also twice as high as for the control group, although it is worth noting that the production data seemingly do not consistently allocate destructed fish to the same data-point for each outbreak.

Among the CMS outbreaks there do not seem to be any significant impact on the growth of the fish, which aligns with farmers saying that the biological implications of CMS is typically only related to mortalities. The smolt yield of the CMS outbreaks was statistically significantly higher than the smolt yield of the control group, by 500 grams. This supports the notion CMS outbreaks typically occur at higher fish weights, making the implications of mortalities higher.

Overall, these analyses, analysis of biological implications align with the economic analysis presented in the preceding section. Table 13 shows the mean and standard error of the control group, as well as the difference to the control group mean, corresponding standard error and p-values of hypothesis t-tests of the difference towards the control group mean for each of the diseases. Appendix 13 displays the STATA-files behind these tests.

Table 13: Statistics of hypothesis testing of the difference of biological implications of outbreaks between outbreaks and the control group.

	Biological implications of outbreaks			
	PD[1]	ISA[1]	CMS[1]	Control group
Length of production cycle (months)	2.489***	-.1865	1.62***	16.24
	(.337)	(1.30)	(.438)	(.187)
Biological feed conversion ratio (bFCR) (x)	.080***	.227***	-0.008	1.135
	(.024)	(.091)	(.0318)	(.019)
Economic feed conversion ratio (eFCR) (x)	.182***	.415***	.0174	1.218
	(.040)	(.1269)	(.043)	(.0180)
Smolt yield (kg)	-.195***	-.990***	.501***	3.767
	(.789)	(.310)	(.1058)	(.0447)
Mortality rate (%)	.022*	.142***	-.022	.1422
	(.012)	(.042)	(.0147)	(.006)
N	307	23	175	857

Standard errors in parentheses. Mean difference to control group displayed (disease - control).
$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: (Norwegian Directorate of Fisheries, 2017, author creation). Note: Only concluded production cycles before YE 2016, and prodcution cycles with complete production data. 1. Terms for PD, ISA, CMS show the difference against the mean of the control group.

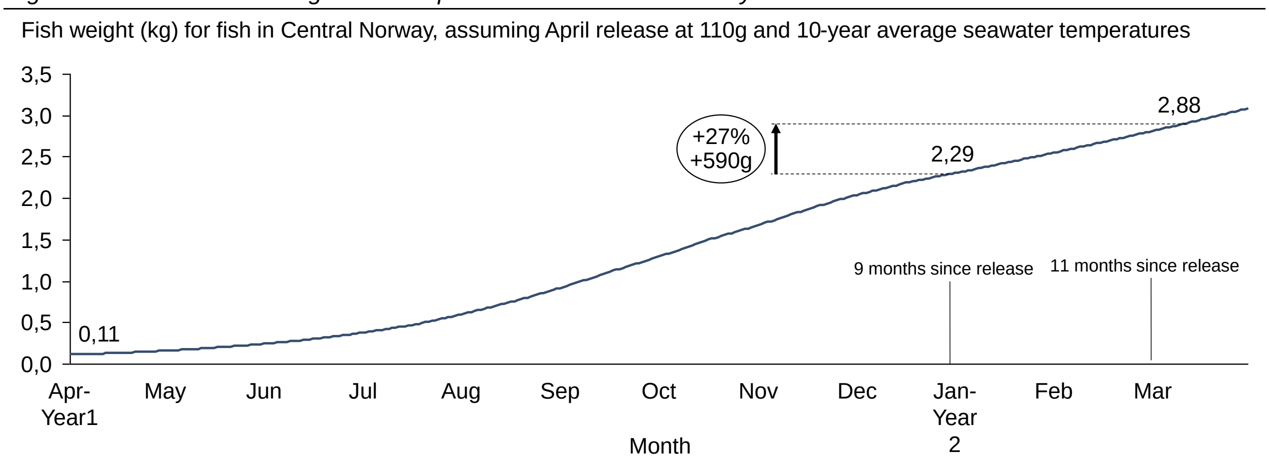
6.6 Results in relation to previous research

The following section discusses the obtained simulation results in relation to previous research, presented for each disease in Chapter 3. The simulated figures in this study display smaller variations in the simulated figures than previous studies that have used a similar methodology. This this study utilized reported biomass figures, which reduces the unpredictability and variation in simulated biological processes.

PD

Aunsmo et. al. (2010) and Pettersen et. al. (2015) estimated that the biological losses was the most important driver for total direct costs associated with PD outbreaks. Similar results was also obtained in this study, although the overall biological losses were lower than those found by Pettersen et. al. (2015). As displayed in Figure 19, the average outbreak that has been included in the analysis model for PD started after approximately eleven months into the production cycle. This figure is higher than the assumption in Pettersen et. al. (2015), of nine months into the production cycle. This period of the production cycle is very important for the fish growth. As illustrated in Figure 27, for fish released into seawater in Central Norway (Trøndelag counties) in April, a two-month difference means a weight gain of close to 0.6 kg. It is therefore expected the overall biological losses associated with PD outbreaks are lower, as a shorter period is experienced with, potentially, weaker growth to reach the desired harvest weight.

Figure 27: Illustration of fish growth for April release in Central Norway for first eleven months in seawater



Source: (Feed producer pers. com., 2017; Lusedata, u.d., author creation). Note: Calculations based on updated growth table per summer 2017 for Central Norway obtained from feed producer, and 10-year average seawater temperatures obtained from Lusedata.

Additionally, the estimates for aggregated implications of PD outbreaks is within the range indicated by Hagen et. al. (2016).

ISA

For ISA outbreaks, the results are, as mentioned in Chapter 3, not directly comparable to any other study. However, due to the severe and arguably less complicated implications of ISA outbreaks, both the seafood media and listed companies reporting have provided estimates of costs related to the disease historically. An analysis of these estimates and quoted figures for specific outbreaks at individual farming sites align closely with the figures presented in this study. Due to the confidentiality agreements regarding the production data, such examples will not be presented to avoid possibility of specific companies or farming sites being identified.

CMS

For CMS, the results are higher than those found by Brun et. al. (2003). A key driver behind the increase is likely to be increasing salmon prices, and thus higher monetary implications of mortalities. Illustratively, Brun et. al.'s (2003) study using production data from 1999 and 2000 indicated that CMS cost the Norwegian salmon farming industry between 33.5 to 66.3 NOKm per year, assuming 3.6% heightened mortality. NVI diagnosed 90 outbreaks of CMS on marine salmonid farms in 2016 (Hjeltnes, et al., 2017). Assuming each of these sites planned to harvest approximately 800.000 individuals at an average weight of 5.5kg, with a salmon price of 55 NOK/kg HOG, and experienced the same increase in mortality due to CMS as estimated by Brun et. al. (2003), the losses for foregone revenue associated with CMS mortality would be closer to 700 NOKm per year. This aligns with the estimates reached in the simulations in this study.

6.7 Limitations and sources of error

There are several limitations and sources of error regarding the analysis performed in this study. Limitations and sources of error not explained in other sections of the study, is presented in the following section.

6.7.1 Indirect economic losses and externalities

A viral disease outbreak does not only have financial implications for the salmon farmer, but also externalities such as layoffs and falling tax income for local communities. Particularly in the county of Nord-Trøndelag, there have been several layoffs due to the "stamping-out" policy towards PD marine SAV-2 outbreaks north of Buholmråsa. Several medium-sized farming groups have their operations within this region, and has accordingly been affected in different ways by PD outbreaks (Aardal, 2013; Hosteland, 2016). Leading up to the new PD regulation implemented in 2017, there was a debate regarding the implications of the PD-policy in Nord-Trøndelag (Berge, 2017; Nodland, 2017). The new PD regulation changed the NFSA's primary policy to now longer automatically result in "stamping out" for this region, which received strong support from the local farmers (Furuset, a, 2017).

The analysis in this thesis does not explore the indirect economic losses of viral diseases outbreaks, such as layoffs and falling tax income for local communities, in more detail.

6.7.2 Accuracy in CMS reporting

Although the outbreak data for CMS was obtained from the NVI, the fact that CMS is not a listed disease can affect the completeness of the dataset. Other than NVI, there are currently two commercial players that provide histopathology and disease diagnosis services for aquaculture in Norway: Pharmaq and Fish Vet Group. Given that the outbreak data from NVI only include the outbreaks diagnosed at NVI's laboratories, the obtained dataset might not provide an exhaustive list of all CMS outbreaks in Norway. Hjeltnes et. al. (2017) noted that, even though NVI receive reports from other laboratories, it is not known if these outbreaks are "in addition to, or overlap partly or completely with outbreaks diagnosed through the NVI system". No other sources of data was possible to acquire on CMS outbreaks during the time available to this project, and the NVI data was consequently the best data available.

6.7.3 Epidemiological limitations

As discussed in section 5.3.2, a limitation with using the crude production data supplied by the NDF is that it is a challenge to attribute weaker biological performance, such as lower growth and mortalities, seen at farming sites to the specific cause. Illustratively, heightened mortality or periods of slower growth in latter stages of the production cycle can for instance be related to handling procures or sea lice treatments. Optimally, one would therefore utilize epidemiological modeling to account for the implications of such biological challenges. The performed simulations do not adjust for this. Even so, these implications are also present in the control group, and one could therefore argue that such implications are controlled for when comparing the realized economic result between the outbreak and the control group.

Fish groups that have been diagnosed with IPN has been reported to experience increased losses associated with HSMI and PD at later stages in the production cycle (Norwegian Veterinary Institute, b, 2015). As previously mentioned, similar challenges are also documented for HSMI outbreaks. The analysis would therefore, optimally, also include and control for outbreaks of HSMI and IPN in the simulation model. However, this was not possible within the timeframe and given the available data of this study. These two diseases can therefore cause underestimations of uncertain magnitudes in the estimated biological losses. Even so, as mentioned in section 3.3.3, the number of IPN outbreaks have fallen in recent years, indicating that the disease is less of a challenge than previously.

6.7.4 Implication of different control group specifications

The analysis performed in section 5.4 to define the control group specification showed that defining the control group based without or without terms related to geography provided similar explanatory power. This section outlines the implications of changing the control group for the overall estimates for biological losses. The other costs components are excluded from this discussion, as they are not impacted by altering the control group.

As displayed in Table 14, changing the control group specification to also filter by geography, in addition to MAB limit and generation, have varying degree of implication between the different diseases. The changes are the largest for PD in 2015, lowering the aggregated estimate with approximately 400 NOKm. Overall, the results appear to be robust and not to change dramatically based on different control group specifications.

Table 14: Total direct costs to salmon farmers – different control group specifications (NOKm)

	PD					ISA					CMS				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Costs to salmon farmers – utilized control group (NOKm)	112	1668	2548	2547	1342		78	279	905	304	446	280	54	747	-107
Costs to salmon farmers – alternative control group[1] (NOKm)	149	1545	2137	2156	1198		84	331	879	298	416	-42	29	768	-180

Source: Study simulations. Note: Negative values mean that estimated direct costs are lower than the respectives control group's economic profit. 1. Alternative control group filtered by both region, MAB limit and fish generation. Utilized control group filtered by MAB limit and fish generation.¨

7. Conclusion

The simulated result in this study highlights the importance of viral diseases in Norwegian salmon aquaculture, and show that the implication of the diseases are indeed severe. The simulations in this study indicate that the total combined direct costs associated with PD, ISA and CMS are of a similar magnitude to four-fifths of direct costs associated with salmon sea lice in Norway, estimated to be approximately five NOKb in 2015 by Iversen et al. (2015). The size of the economic losses, and risks and uncertainties related to each outbreak's clinical- and economic implications indicate that salmon farmers should continue to combat the disease with the tools and means available. The analysis consequently show that economic losses associated with viral diseases in Norwegian salmonid aquaculture is significant, and affect the value creation in the industry adversely.

Given the importance of control measures such as zone control, fallowing regimes and protocols in mitigation of viral disease outbreaks, the results of this study illustrate the importance for governmental bodies, such as the NSFA, the NVI and the NDF, to be both active and cooperative in developing and maintaining regulation and control of the industry. Farmers' interest to maximize profits and meet shareholder's requirement for return on invested capital should optimally be balanced with a strong commitment to biology- and disease mitigation investments. Norwegian farming companies generally show a strong commitment and interest in improving biology, most recently illustrated by the company's interest and desire to invest in development licenses.

The government has taken an important step to limit the awarding of growth opportunities to farmers that maintain a good biological situation, with the introduction of the Norwegian traffic light system. However, at the time of writing the biological criteria only includes sea lice levels. There are inherent complexities for the government to regulate viral diseases, given the challenges of limiting and understanding the spreading of diseases. It is the impression of the this study that it therefore is unlikely that viral diseases will be regulated much differently in the future, and also unlikely that viral diseases will for instance be included in the traffic light system. The policy focus will likely remain on eradication and control efforts.

There are many complexities for stakeholders looking to change policy or regulation regarding viral diseases. Combating and controlling viral diseases is arguably important for the sustainability and durability of smaller salmon farming companies. Viral diseases can particularly be critical for smaller salmon producers, as these companies have fewer sites and licenses to spread the risk. A large farmer, with multiple sites and licenses, can increase the production on other sites in the event of an outbreak, reducing the overall implications, although somewhat delaying the value creation. Given the current frequency of outbreaks, and in the event of periods with sustained lower-than-current profitability, it is not unthinkable that a viral disease outbreak can challenge the solidity and liquidity position of smaller salmon farming companies.

Although large companies in the industry, such as Austevoll Seafood and Marine Harvest, have issued bonds in the past, the salmon farming industry in Norway typically use bank debt for debt funding. Higher idiosyncratic risk, such as a viral disease outbreak, should in theory have implications for the interest cost for an affected farmer (Johnsen, 2016). However, viral diseases do in isolation not seem to affect the opportunities to secure financing and the related interest cost for farmers. Two of the largest Norwegian banks with loan portfolios towards the salmon farming industry confirmed, separately, that they do, for instance, analyze of the farming companies' site structure (geographic spread, proximity, fjord systems) when evaluating a potential loan or facility. Illustratively, one of the banks operated with an internal policy of only offering loans to farming companies that had more than a defined lower limit of sites available for farming operations. However, the banks said that they value long-term relationships with their customers, and thus typically do not directly change either interest costs or covenants for farmers that had experienced viral disease outbreaks.

This study does not seek to discuss or evaluate potential solutions and mitigation techniques that can affect the incidence rate and, or economic implications of viral disease outbreaks. However, the simulations and results collected in this thesis gives an indication that there should be a high willingness to pay for a new or improved solution to mitigate risks and uncertainties, and lower implications, caused by PD, ISA, CMS and other viral diseases. The conclusions reached in this thesis could therefore, potentially, be a source of inspiration and information to companies and individuals that are developing such solutions.

The study suggest three potential dimensions of further extensions to the methodology applied in this thesis. Available data and resources limit and dictate the likelihood of implementation for each.

Extension to cover more diseases

The simulations in this thesis has focused on PD, ISA and CMS. However, dependent on data availability, other viral diseases could be analyzed with a similar methodology.

Extension to more countries

As described in the introduction to this thesis, the lack of publicly available data sources for production- and disease data from other countries than Norway, limits the possibility to complete this analysis for other countries. However, if governments and industry in other production regions join forces to build the same set of transparent data sharing solutions as in Norway; this exercise could also be completed for other countries in the future. The insights provided by studies such as this one should be desirable by the salmon farming industry in other countries to evaluate the implications and the regulations to combat the diseases.

Detailed epidemiological modeling

The applied methodology in this thesis can be utilized in combination with higher levels of epidemiological modeling than was feasible for this thesis. The production data used in this thesis was crude, and thus was not optimal for allocating cause-specific mortality. Aunsmo et. al. (2008) documented that fish health professionals are able to categorize the cause of death with a “very high likelihood” in 92% of instances. Bleie & Skrudland (2014) completed a nationwide study of similar vision. Although likely a time-consuming and costly exercise, combining the economical methodology in this thesis, and in similar works, with detailed epidemiological modeling will likely improve the conclusions.

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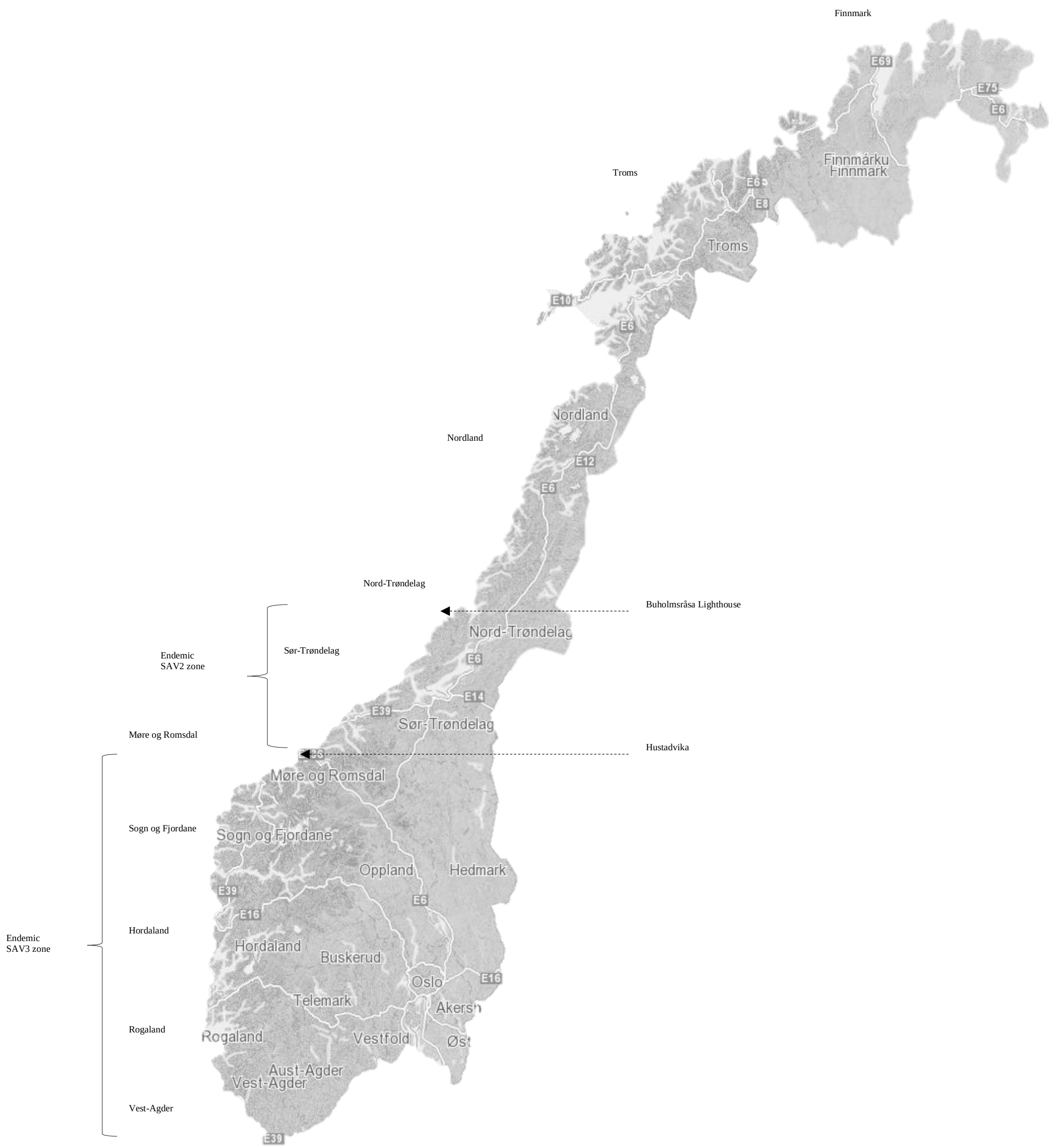
9. Appendix

Appendix 1: Norwegian geography

Overview of counties and key geographical areas in Norway.



Source: (BarentsWatch, u.d., author creation)

Overview of production areas in Norway.

Source: (Norwegian Directorate of Fisheries, 2017., author creation)

Appendix 2: Detailed overview of model components

	Cost component	Calculation methodology	Sources
	Sales revenue	- HOG converted harvest volume x Share in each quality category (PERT-dist.) - Gutted volume in each quality category x Respective salmon price (corresponding month and weight)	Harvest volume: *NDF (2017)* Salmon price: *Nasdaq / FHL (u.d)* Share in each quality category:*Pettersen et. al. (2016)*
-	**Smolt cost**	- Number of smolts released in each production cycle x Price per smolt	Smolt release: *NDF (2017)* Price per smolt: *Iversen et. al. (2015) / Kontali pers. com. (2017)*
-	**Other fixed costs**	- Number of smolts released in each production cycle x Cost per fish other fixed costs	Smolt release: *NDF (2016)* Cost other fixed cost: *Kontali pers. com (2017)*
-	**Maintenance cost**	- Maintenance cost of on-site equipment and installations per production cycle (PERT-dist.)	*Pettersen et. al. (2016)*
-	**Grow-out feed**	- Volume of grow-out feed fed x Price of grow out feed	Volume: *NDF (2017)* Price of feed: *NDF (2016)*
-	**Mechanical treatment(s) lice**	- (Number of full site mechanical treatments x Number of operational cages + Number of part-site mechanical treatments x Number of operational cages x Share of site treated when only parts are treated (PERT-dist.)) x Cost per cage (PERT-dist.))	Treatment number and extent: *BarentsWatch* Share of site treated: *Salmon farmers communication* Cost per cage: Næstvold (2017)
-	**Medical treatment(s) lice**	- (Number of full site medical treatments x Biomass at site + Number of part-site medical treatments x Biomass at site x Share of treated when only parts are treated (PERT-dist.)) x Respective /kg cost of active substance	Treatment number and extent: B*arentsWatch* Share of site treated: *Salmon farmer communication* Cost active substance: *Iversen et. al. (2015)*
-	**Cleaner fish cost**	- Number of cleaner fish released x Price per cleaner fish	Cleaner fish release: *BarentsWatch* Price per cleaner fish: *Iversen et. al. (2015)*
-	**Feed lice treatment cost**	- Volume of sea lice treatment feed fed x Price of sea lice treatment feed	Treatment number and extent: *BarentsWatch* Cost of sea lice feed, length of feeding period: *Salmon farmer communication*
-	**Insurance cost**	- Insurance cost per kg of harvested salmon x Harvest salmon (wfe)	Insurance premium: *NDF (2016)* Harvest volumes: *NDF (2017)*
+	**Insurance payout**	- Mortality count at pen level >30% within 90 day period x Weight of mortalities x Insurance value for respective weight class	Mortality by pen: *NDF (2017)* Insurance values: *Insurance companies communication*
=		**Economic result (EBIT)**	

PERT-dist. *Variable is PERT-distributed in simulations*

Appendix 3: Overview of questionnaire for salmon farmers

Section	Question	Answer specification
Downgrading and price achievement		
1.1	What share (%) of harvest volumes is typically in each of the categories after a PD-outbreak (% of harvested biomass)	Most likely – Superior, Ordinary, Production, Condemned
1.2	How large of a reduction in achieved sales price is normally experienced with a salmon price at 40 NOK/kg? (NOK/kg gutted)	Most likely – Superior, Ordinary, Production
1.3	How large of a reduction in achieved sales price is normally experienced with a salmon price at 50 NOK/kg? (NOK/kg gutted)	Most likely – Superior, Ordinary, Production
Biological prevention and reaction costs		
2.1	What is the typical ISA-surveillance cost (scanning and labor) per farming site per production cycle	Minimum, most likely, maximum (NOKm)
2.2	What are typical maintenance cost on nets, pens, feed barges, feeding systems etc. per farming site per production cycle	Minimum, most likely, maximum (NOKm)
2.3	What is typically the cost for handling of mortality	Minimum, most likely, maximum (NOK/kg)
2.4	What is typically the extraordinary harvest cost during outbreaks of ISA, PD (cleaning, densification)	Minimum, most likely, maximum (NOK/kg)
2.5	What is typically the extraordinary labor cost associated with handling of ISA, PD outbreaks	Minimum, most likely, maximum (NOKm)
Decision process for SAV3 (South of Hustadvika) and SAV2 (South of Buholmsråsa)		
3.1	Which level of the organization will take the decision for vaccination of the fish	Position title
3.2	Which level of the organization will take the decision for further production or pre-scheduled harvest of the fish	Position title
Parameters in sea lice mitigation and PD-feeding		
4.1	What is the average cost for a mechanical delousing treatment (farming site equivalent)	Minimum, most likely, maximum (NOKm)
4.2	What is the average cost for a medical delousing treatment (farming site equivalent)	Minimum, most likely, maximum (NOKm)
4.3	What share of a site is typically treated if only "parts" of the site is treated (with reference to BarentsWatch data)	Minimum, most likely, maximum (%)
4.4	How long does a sea lice feed treatment period typically last? (Number of days)	Minimum, most likely, maximum (days)
4.5	How long does a PD-feed feed period typically last? (Number of days)	Minimum, most likely, maximum (days)
4.6	What is typically the price increase per kilo of sea lice treatment feed relative to grow-out feed?	NOK/kg
4.7	What is typically the price increase per kilo of functional PD-feed relative to grow-out feed?	NOK/kg

Appendix 4: Overview of personal communication sources

Company	Position
Feed producer	Health Manager, Grow-out feed Manager
Vaccine producer	Product manager, KAM, R&D manager
Vaccine producer, a	Sales director, KAM
Salmon farmer (Expert panel participant)	CFO
Salmon farmer, a	Fish Health Manager
Insurance company	Risk Advisor, Underwriter
Insurance company, a	Practice area head
Kontali Analyse AS	Analyst
Norwegian Food Safety Authority	Senior Advisor
Norwegian Bank	Seafood division banker
Norwegian Bank, b	Seafood division banker

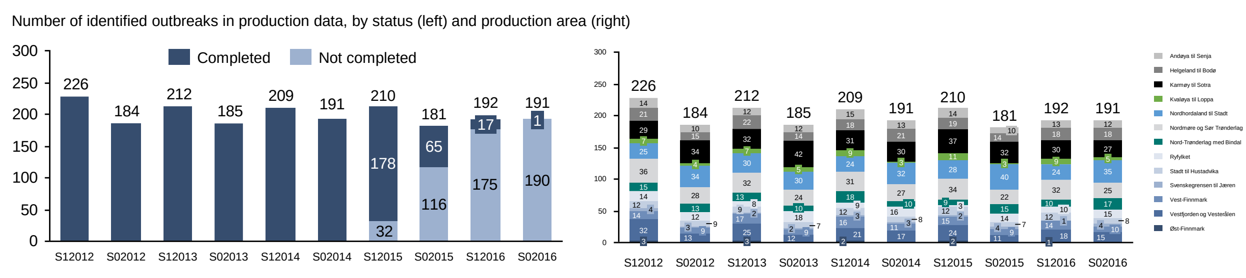
Appendix 5: Overview of biological production data

Model parameter	Unit	Coverage and dataset details
Year	Year	
Month	Month	- All seawater salmon farms in Norway 2012 – 2016
Organization number	ID	
Owner company	Name	- Monthly data
Site number	ID	
Site name	Name	- ≈ 13.000 unique pens on ≈ 1.200 sites
Pen ID	ID	
Pen volume	Volume	- ≈ 5.500.000 data points
Fish species	Name	
Fish release	# of individuals	- Incorporated and analyzed in Microsoft Excel
Number of fish individuals	"	
Biomass	Kg	
Feed consumption	Kg	
Loss – mortalities	# of individuals	
Loss – condemned	"	
Loss – escapes	"	
Loss – other	"	
Harvested fish	"	
Harvest volume	Kg	
Moved fish volume	Kg	
Feed type	ID	
Municipality	ID	

Source: (Norwegian Directorate of Fisheries, 2017)

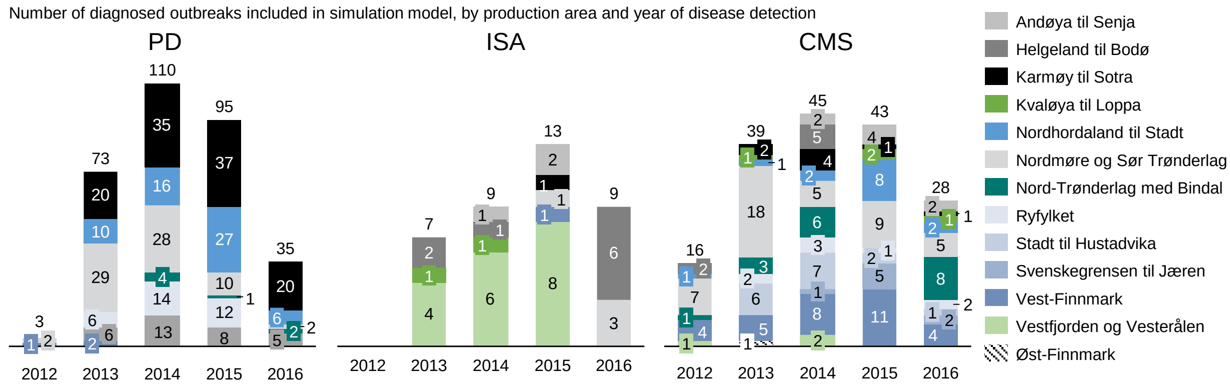
The figure below provides an overview of the production cycles that were identified in the biological production data. Only completed production cycles were included in the simulations.

Overview of production cycles identified in biological production data



Source: (Norwegian Directorate of Fisheries, 2017, author creation and analysis)

Appendix 6: Overview of included viral disease outbreaks



Source: (Norwegian Veterinary Institute, c , 2017; BarentsWatch, n.d., author creation)

Appendix 7: Estimation of medical delousing treatment costs

Cost per medical delousing of sites in Norway

Inputs

Component	Parameter	Unit
Total site biomass (base model)	4 000	tonnes
Day rate service vessel	30 000	NOKk
Day rate wellboat	75 000	"
Labor hourly rate (NOK/hour)	300	NOK
Day length labor	11	hours

Product:	H202	Betamax	Salmosan	Alfamax	
Cost of substance					
Substance	H202	Cypermetrin	Deltametrin	Azametifos	
Total cost (NOKk)	1 950 000	390 000	400 000	489 000	
Cost per kilo (NOK/kg)	**0.49**	**0.10**	**0.10**	**0.12**	A
Labor cost					
Days needed (days)	4.5	3.5	3.5	3.5	
Number of FTEs	13	7	7	7	
Total labor cost (NOKk)	193 050	80 850	80 850	80 850	
Cost per kilo (NOK/kg)	**0.05**	**0.02**	**0.02**	**0.02**	B
Vessel cost					
Number of service vessel(s)	3	3	3	3	
Number of wellboat(s)	1	0	0	0	
Total vessel cost (NOKk)	742 500	315 000	315 000	315 000	
Cost per kilo (NOK/kg)	**0.19**	**0.08**	**0.08**	**0.08**	C
Total cost per kilo (NOK/kg)	**0.72**	**0.20**	**0.20**	**0.22**	A+B+C

Cost per kg at different site biomass sizes*

		Delousing product			
		H202	Betamax	Salmosan	Alfamax
Site biomass	1 000	1.42	0.49	0.50	0.52
	2 000	0.96	0.30	0.30	0.32
	3 000	0.80	0.23	0.23	0.25
	4 000	0.72	0.20	0.20	0.22
	5 000	0.67	0.18	0.18	0.20
	6 000	0.64	0.16	0.17	0.19
	7 000	0.62	0.15	0.16	0.18
	8 000	0.60	0.15	0.15	0.17

*Calculations asssumes unchanged need for labor and vessels at the different biomass levels. A linear change in use of active substance also assumed

Source: (Iversen, et al., 2015, author creation)

Appendix 8: Estimation of fixed cost per fish

Estimated fixed cost per fish

		2012	2013	2014	2015	2016	Source
Harvest volume	tonnes	1 259 770	1 207 430	1 295 105	1 315 751	1 260 653	Norwegian Directorate of Fisheries
Smolt release	k	283 778	298 320	308 382	315 159	306 968	"
0-year generation harvest	"	689	380	1 581	8 502	3 070	"
1-year generation harvest	"	161 553	157 827	174 418	193 307	198 550	"
2-year generation harvest	"	144 456	131 657	125 262	123 522	113 494	"
Total number of fish harvested		**306 697**	**289 864**	**301 261**	**325 332**	**315 114**	
Ordinary labor cost	NOK/kg	1.55	1.63	2.10	2.30	2.80	Kontali Analyse
Depreciation cost	"	1.15	1.23	1.26	1.58	1.58	"
Total labor and depreciation cost per kg of harvest	"	2.70	2.86	3.36	3.88	4.38	"
Total labor and depreciation cost (NOKm)	NOKm	3 398	3 457	4 357	5 108	5 525	"
		2012-G	**2013-G**	**2014-G**	**2015-G**	**2016-G**	
Total labor and depreciation cost per fish by generation	NOK/fish	13.02	14.96	16.30	17.36	17.36	Author estimates

$$\textit{Calculation of cost per fish by generation} = \frac{\sum_{i=0}^{n} \%\ of\ annual\ harvest\ (k\ individuals)_i\ x\ Total\ annual\ labor\ and\ depreciation\ cost\ of\ harvested\ fish_i}{Generational\ smolt\ release\ (annual)}$$

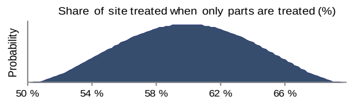
Note: 2016-G estimate similar to 2015-G estimate due to lack of published data.

Appendix 9: Overview of simulation probability distributions

The following appendix provides an overview of the probability distributions used in the simulations, as they were inputted in Oracle Crystal Ball (Oracle Corp., u.d.).

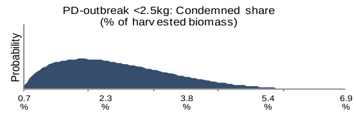
Overview of Oracle Crystal probabilty distributions utilized in simulation model

Share of site treated for lice when only parts are treated



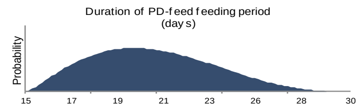
BetaPERT distribution	
Minimum	50 %
Likeliest	60 %
Maximum	70 %

PD-outbreak <2.5kg: Condemned share



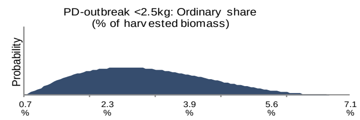
BetaPERT distribution	
Minimum	0.7 %
Likeliest	1.9 %
Maximum	6.9 %

Duration of PD-feed feeding period



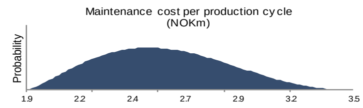
BetaPERT distribution	
Minimum	15
Likeliest	20
Maximum	30

PD-outbreaks <2.5kg: Ordinary share



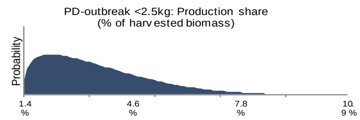
BetaPERT distribution	
Minimum	0.7 %
Likeliest	2.7 %
Maximum	7.1 %

Maintenance cost per production cycle



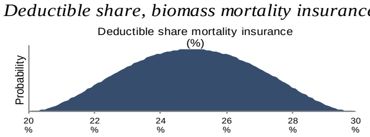
BetaPERT distribution	
Minimum	1.9
Likeliest	2.5
Maximum	3.5

PD-outbreaks <2.5kg: Production share



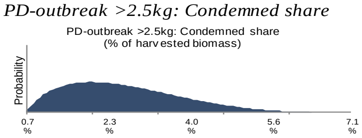
BetaPERT distribution	
Minimum	1.4 %
Likeliest	2.2 %
Maximum	10.9 %

Deductible share, biomass mortality insurance



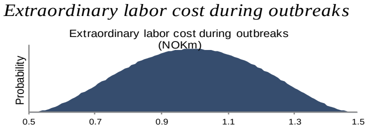
BetaPERT distribution	
Minimum	20 %
Likeliest	25 %
Maximum	30 %

PD-outbreak >2.5kg: Condemned share



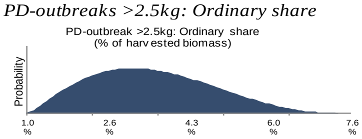
BetaPERT distribution	
Minimum	0.7 %
Likeliest	2.0 %
Maximum	7.1 %

Extraordinary labor cost during outbreaks



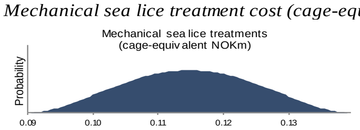
BetaPERT distribution	
Minimum	0.5
Likeliest	1.0
Maximum	1.5

PD-outbreaks >2.5kg: Ordinary share



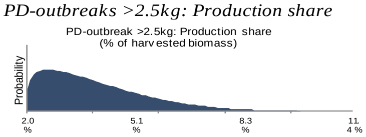
BetaPERT distribution	
Minimum	1.0 %
Likeliest	3.1 %
Maximum	7.6 %

Mechanical sea lice treatment cost (cage-equivalent)



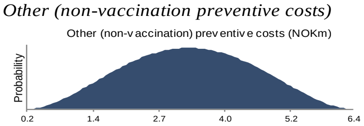
BetaPERT distribution	
Minimum	0.09
Likeliest	0.12
Maximum	0.14

PD-outbreaks >2.5kg: Production share



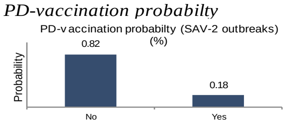
BetaPERT distribution	
Minimum	2.0 %
Likeliest	2.6 %
Maximum	11.4 %

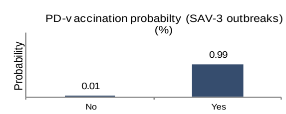
Other (non-vaccination preventive costs)



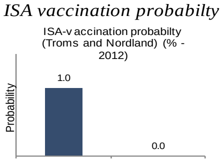
BetaPERT distribution	
Minimum	0.17
Likeliest	3.28
Maximum	6.45

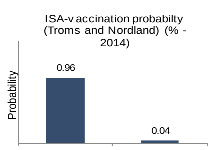
PD-vaccination probabilty

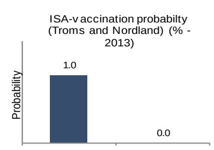


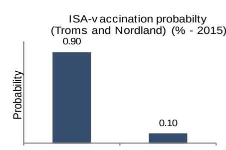


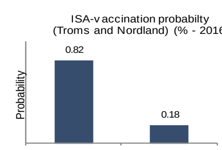
ISA vaccination probabilty





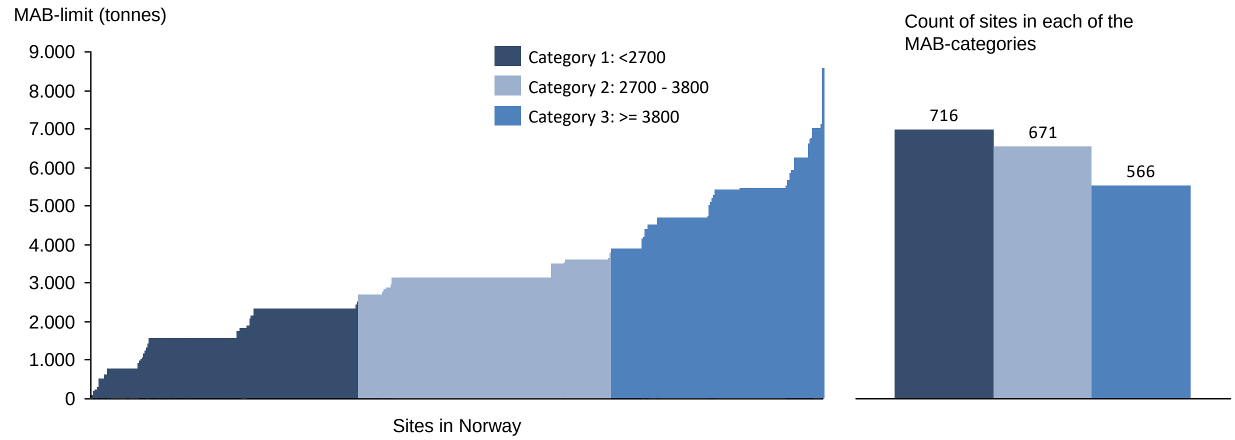






Source: (Oracle Corp., u.d., author creation)

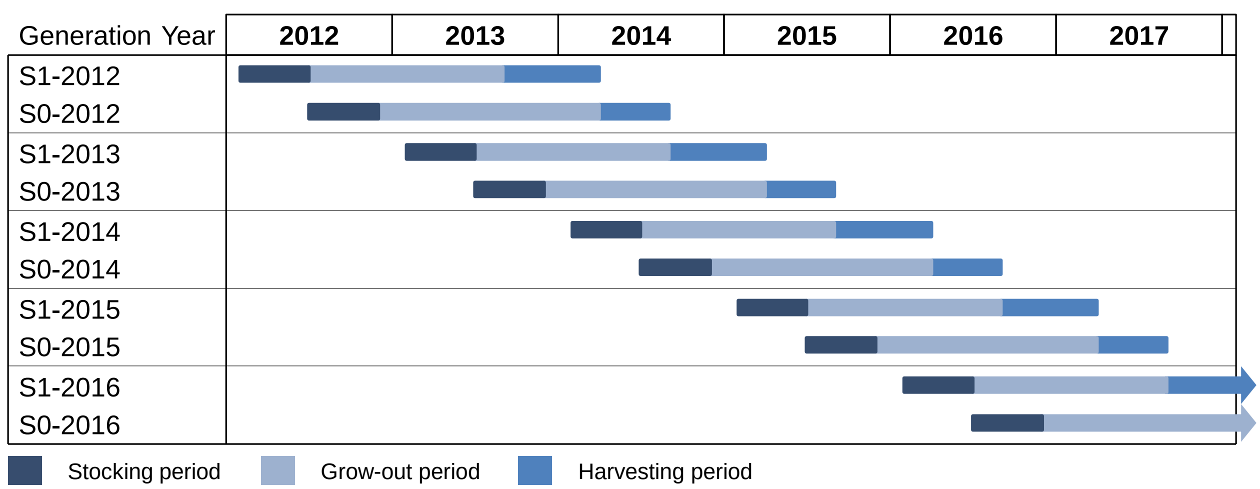
Appendix 10: Norwegian farming sites' MAB limit



Source: (Norwegian Directorate of Fisheries, u.d., author creation). Note: Data as of September 2017. Site specific MAB limits might have changed throuhgout the simulated years, latest figures used. For sites that have been democomissoned during the simulated years, the site MAB limit was manually inputted, with data from BarentsWatch.

Appendix 11: Norwegian biomass generation calendar

Approximate biomass generation calendar for Norwegian Atlantic salmon. Particularly the harvest period varies based on release weight, desired harvest weight and other factors.



Source: (Kontali Analyse AS, a, 2017, author creation)

Appendix 12: Estimated economic losses for outbreaks

In compliance with several confidentially agreements with different institutions signed by the participants in this project, this thesis will not provide any additional detail that allows for identification of the specific site or company included in either the control group or among the outbreaks. All values displayed below are mean values of simulated figures measured in NOKm. The following abbreviations are used to compressed the table: BL = Biological losses, T = Cost of treatment, P = Cost of prevention, EC = Other extraordinary costs and IP = Insurance payout. The order of the outbreaks below are project-internal numbering, and not related to date, region or other sorting criteria.

Outbreak #	Disease	BL	T	P	EC	IP
1	PD	-6.8	0.8	4.1	3.6	0.4
2	PD	-1.4	1.4	4.4	3.6	0.0
3	PD	56.3	1.1	4.4	3.1	0.8
4	PD	31.0	0.6	4.5	3.8	1.3
5	PD	26.9	0.0	3.5	3.3	0.0
6	PD	-18.9	0.4	4.7	3.9	0.0
7	PD	11.1	1.0	5.1	0.0	0.0
8	PD	-2.5	0.5	3.9	3.6	0.0
9	PD	23.5	2.7	6.1	9.6	0.0
10	PD	143.2	0.0	3.6	1.0	0.0
11	PD	-11.1	0.0	4.8	3.3	0.0
12	PD	25.8	4.1	5.0	5.4	0.0
13	PD	-20.8	1.4	4.6	6.6	0.0
14	PD	23.2	0.5	4.5	3.5	0.0
15	PD	61.6	1.2	6.0	1.0	0.0
16	PD	28.5	2.0	6.4	9.5	0.0
17	PD	8.2	2.8	5.3	5.6	0.0
18	PD	62.6	2.3	4.7	4.9	3.6
19	PD	44.4	1.2	4.6	3.5	0.0
20	PD	5.7	0.0	3.6	5.1	0.0
21	PD	69.3	0.0	3.6	1.0	0.0
22	PD	22.0	1.4	4.7	4.4	0.0
23	PD	83.1	1.4	4.6	3.1	0.0
24	PD	-10.2	1.4	4.2	4.6	0.0
25	PD	-4.5	0.0	3.6	4.9	1.2
26	PD	72.8	0.9	4.6	3.2	3.4
27	PD	-34.9	0.0	3.7	11.9	0.0
28	PD	-59.6	0.0	3.6	11.3	0.0
29	PD	1.9	0.0	3.5	10.2	0.0
30	PD	-43.1	4.9	6.3	11.2	0.0
31	PD	36.9	3.6	5.9	6.9	3.9
32	PD	24.4	2.7	4.4	4.6	0.0
33	PD	72.7	8.0	5.7	8.5	0.0
34	PD	-39.4	0.0	3.6	8.5	0.0
35	PD	-93.4	0.0	3.6	10.1	0.0
36	PD	33.7	0.0	3.5	6.6	0.0
37	PD	-3.4	0.2	3.9	2.1	0.0
38	PD	-0.9	0.2	4.4	3.4	0.0
39	PD	-92.5	2.0	4.8	6.2	0.0
40	PD	34.9	1.5	5.0	4.6	8.3
41	PD	22.1	2.1	3.6	3.6	0.0
42	PD	30.6	0.6	4.1	2.8	2.6
43	PD	39.2	1.5	6.7	11.7	0.0
44	PD	4.0	4.6	6.6	7.4	0.0
45	PD	0.3	2.8	4.5	5.1	0.0
46	PD	73.0	0.4	5.7	5.6	2.3
47	PD	11.2	0.6	3.8	2.2	0.0
48	PD	-4.9	0.7	3.7	3.6	0.0
49	PD	71.6	3.7	4.0	4.8	0.0
50	PD	11.5	0.0	3.6	9.4	0.0
51	PD	18.2	0.0	3.5	6.1	0.0

Outbreak #	Disease	BL	T	P	EC	IP
265	PD	-7.6	0.0	5.4	1.0	0.0
266	PD	-17.9	3.3	4.9	5.8	0.0
267	PD	3.0	0.5	3.8	3.0	0.0
268	PD	15.5	2.0	4.6	3.6	0.0
269	PD	-24.5	1.5	4.8	4.6	0.0
270	PD	19.5	3.0	4.8	4.9	0.0
271	PD	21.0	3.2	5.1	7.2	0.0
272	PD	-1.4	0.7	5.4	7.5	0.0
273	PD	-10.3	0.7	5.2	6.7	1.2
274	PD	69.7	1.0	4.3	2.7	0.0
275	PD	9.4	1.0	4.4	3.6	0.0
276	PD	50.2	0.0	4.7	1.0	0.0
277	PD	19.5	1.7	5.1	5.0	0.0
278	PD	27.3	0.3	3.5	1.3	0.0
279	PD	7.3	0.7	3.8	2.8	0.0
280	PD	20.8	4.3	6.5	12.0	0.0
281	PD	43.2	0.0	5.2	6.5	0.0
282	PD	45.6	2.2	5.0	6.0	1.0
283	PD	-51.1	0.0	3.6	1.0	0.0
284	PD	1.8	1.1	4.0	3.8	0.0
285	PD	13.9	3.6	4.2	6.9	0.0
286	PD	55.0	1.4	5.1	5.0	0.0
287	PD	56.1	1.4	4.6	5.1	1.4
288	PD	1.5	1.0	4.0	5.1	0.5
289	PD	13.6	3.8	8.8	8.7	0.0
290	PD	16.4	0.3	3.7	1.8	0.0
291	PD	6.6	0.0	4.7	1.0	0.0
292	PD	17.9	2.3	5.1	7.5	0.0
293	PD	8.1	0.4	3.7	2.3	0.0
294	PD	33.7	3.2	4.9	6.0	0.0
295	PD	43.5	2.0	5.1	5.3	0.0
296	PD	28.5	0.4	4.3	4.1	0.0
297	PD	-8.7	2.9	4.7	5.3	0.0
298	PD	12.7	1.7	4.7	5.3	0.0
299	PD	14.0	0.6	3.8	1.9	0.0
300	PD	44.9	0.9	4.7	4.0	0.0
301	ILA	9.8	0.0	3.3	7.7	1.2
302	ILA	-39.1	0.0	3.3	8.1	1.2
303	ILA	53.0	0.0	3.2	6.6	1.5
304	ILA	32.8	0.0	3.3	1.5	1.3
305	ILA	14.5	0.0	3.3	2.1	1.9
306	ILA	31.7	0.0	3.3	4.7	6.4
307	ILA	-3.6	0.0	3.3	2.4	1.2
308	ILA	70.5	0.0	3.3	1.0	10.6
309	ILA	22.3	0.0	3.3	3.5	7.1
310	ILA	24.6	0.0	3.2	1.7	4.5
311	ILA	120.9	0.0	3.4	1.0	31.3
312	ILA	89.2	0.0	3.3	6.9	1.2
313	ILA	66.7	0.0	3.3	3.5	1.2
314	ILA	14.5	0.0	3.3	1.0	1.1
315	ILA	32.8	0.0	3.3	3.7	1.2

52	PD	13.1	0.5	3.4	1.6	0.0	316	ILA	2.8	0.0	3.3	6.6	2.9
53	PD	183.4	0.0	3.7	1.0	0.0	317	ILA	74.7	0.0	3.3	1.5	1.2
54	PD	8.0	0.5	4.5	3.5	0.0	318	ILA	145.4	0.0	3.3	2.4	22.0
55	PD	-12.7	0.0	3.5	10.6	0.0	319	ILA	8.7	0.0	3.3	1.8	1.2
56	PD	47.2	0.0	3.7	13.9	0.0	320	ILA	108.9	0.0	3.2	3.3	11.5
57	PD	22.1	0.0	3.8	2.2	0.0	321	ILA	35.9	0.0	3.3	1.8	1.6
58	PD	-1.0	1.4	4.2	3.5	0.0	322	ILA	-8.6	0.0	3.3	6.3	1.2
59	PD	-5.3	0.0	3.8	9.0	0.0	323	ILA	-37.1	0.0	3.2	4.7	1.2
60	PD	20.9	0.0	3.5	8.1	0.0	324	CMS	-30.7	0.0	3.3	1.0	0.0
61	PD	1.3	1.7	5.3	6.1	1.8	325	CMS	24.1	0.0	3.3	1.0	0.0
62	PD	55.8	0.0	3.6	1.0	0.0	326	CMS	-5.7	0.0	3.3	1.0	0.0
63	PD	77.4	2.1	4.7	4.6	0.0	327	CMS	111.0	0.0	3.3	1.0	0.0
64	PD	114.6	0.0	3.6	1.0	0.0	328	CMS	86.3	0.0	3.4	1.0	0.9
65	PD	-4.3	3.4	4.8	6.2	0.0	329	CMS	-8.0	0.0	3.2	2.9	0.0
66	PD	128.3	0.0	3.7	1.0	0.0	330	CMS	-32.1	0.0	3.3	1.0	0.1
67	PD	-0.1	2.7	5.6	7.9	0.0	331	CMS	73.9	0.0	3.3	1.0	0.0
68	PD	-26.1	5.1	4.0	10.0	0.0	332	CMS	35.1	0.0	3.3	1.0	0.0
69	PD	8.4	0.0	5.6	1.0	1.5	333	CMS	45.5	0.0	3.2	1.0	1.0
70	PD	37.1	0.0	4.5	1.0	0.0	334	CMS	-17.9	0.0	3.3	1.0	0.0
71	PD	25.5	1.8	4.5	4.7	0.0	335	CMS	41.5	0.0	3.4	1.0	0.0
72	PD	19.5	0.9	4.9	5.5	1.4	336	CMS	49.7	0.0	3.3	1.0	0.7
73	PD	16.2	1.5	3.8	4.2	1.3	337	CMS	-24.9	0.0	3.3	1.0	0.0
74	PD	37.1	0.0	3.7	6.7	0.0	338	CMS	14.8	0.0	3.3	1.0	0.2
75	PD	7.7	0.2	4.7	5.2	0.0	339	CMS	16.1	0.0	3.2	1.0	0.0
76	PD	1.4	0.5	3.7	3.0	0.0	340	CMS	-25.1	0.0	3.3	1.0	0.0
77	PD	35.0	2.3	6.4	5.7	0.0	341	CMS	-15.1	0.0	3.4	1.3	0.0
78	PD	25.8	1.7	5.0	5.4	0.4	342	CMS	-14.4	0.0	3.3	1.0	0.0
79	PD	20.1	1.6	6.3	5.7	0.0	343	CMS	32.2	0.0	3.3	1.0	0.0
80	PD	26.1	0.9	4.5	3.7	0.0	344	CMS	76.9	0.0	3.3	1.0	0.0
81	PD	3.6	1.6	4.8	5.9	1.9	345	CMS	49.3	0.0	3.2	1.0	0.0
82	PD	-19.4	0.0	6.8	1.0	0.0	346	CMS	-33.9	0.0	3.3	1.0	0.0
83	PD	24.9	4.7	4.0	5.2	0.0	347	CMS	-46.6	0.0	3.2	1.5	0.0
84	PD	50.1	1.5	4.7	4.5	0.0	348	CMS	-39.3	0.0	3.3	5.3	0.0
85	PD	-67.9	2.6	9.1	12.8	0.0	349	CMS	1.4	0.0	3.3	1.0	1.3
86	PD	-18.7	0.6	4.4	5.6	0.0	350	CMS	-17.7	0.0	3.3	1.0	0.0
87	PD	-23.0	0.0	5.0	1.0	0.0	351	CMS	17.7	0.0	3.3	2.2	0.0
88	PD	15.5	1.2	6.6	5.9	0.0	352	CMS	-18.2	0.0	3.3	1.4	0.0
89	PD	-7.1	1.8	3.7	4.1	0.0	353	CMS	68.1	0.0	3.3	1.0	0.0
90	PD	-7.9	0.2	4.5	4.0	0.0	354	CMS	-10.0	0.0	3.3	1.0	0.0
91	PD	6.8	1.6	4.5	3.5	0.0	355	CMS	41.4	0.0	3.3	1.0	0.0
92	PD	50.0	1.1	3.7	3.5	4.3	356	CMS	29.6	0.0	3.3	1.0	0.0
93	PD	41.2	1.2	5.5	3.9	0.0	357	CMS	-0.6	0.0	3.4	1.2	0.0
94	PD	8.8	0.0	3.6	8.8	0.0	358	CMS	27.1	0.0	3.3	1.0	0.0
95	PD	4.8	1.0	4.7	4.3	0.0	359	CMS	-18.8	0.0	3.3	1.0	0.0
96	PD	-10.1	1.9	3.2	2.6	0.0	360	CMS	47.7	0.0	3.3	1.0	0.0
97	PD	60.1	0.0	6.3	6.4	2.1	361	CMS	-18.2	0.0	3.3	1.0	0.0
98	PD	16.5	1.2	4.5	5.1	2.9	362	CMS	22.1	0.0	3.3	1.5	0.0
99	PD	21.7	0.4	4.2	3.4	0.5	363	CMS	-1.0	0.0	3.3	1.0	0.0
100	PD	22.9	2.4	4.6	4.1	1.4	364	CMS	18.6	0.0	3.2	1.0	0.0
101	PD	2.1	1.1	3.3	2.8	0.0	365	CMS	75.3	0.0	3.2	1.0	1.4
102	PD	18.4	1.3	4.7	4.0	0.0	366	CMS	-27.8	0.0	3.3	1.0	1.0
103	PD	-0.4	0.8	4.0	3.6	0.0	367	CMS	5.3	0.0	3.3	1.0	0.0
104	PD	-17.6	0.0	3.6	10.4	0.0	368	CMS	24.4	0.0	3.3	1.7	0.0
105	PD	0.0	1.8	4.6	3.1	0.0	369	CMS	22.8	0.0	3.3	1.0	0.0
106	PD	-0.9	2.1	5.3	4.4	0.0	370	CMS	-1.6	0.0	3.3	1.0	0.0
107	PD	47.0	0.5	4.6	1.7	0.0	371	CMS	-31.6	0.0	3.3	1.3	2.8
108	PD	-5.1	1.5	4.2	2.8	0.0	372	CMS	-29.9	0.0	3.4	1.0	0.0
109	PD	16.9	1.8	4.1	2.7	0.0	373	CMS	-55.0	0.0	3.3	2.0	0.0
110	PD	-4.1	0.3	4.2	3.6	0.0	374	CMS	-79.8	0.0	3.3	1.9	0.0
111	PD	68.6	2.3	5.4	5.6	0.0	375	CMS	-14.0	0.0	3.3	1.4	0.0
112	PD	17.8	1.3	5.2	7.5	0.0	376	CMS	18.8	0.0	3.4	1.0	0.0
113	PD	20.8	0.8	4.8	3.8	0.0	377	CMS	19.6	0.0	3.2	1.0	0.0
114	PD	18.2	0.4	4.4	1.8	1.6	378	CMS	7.1	0.0	3.3	1.0	0.0
115	PD	-2.0	2.5	4.2	4.4	0.0	379	CMS	-2.9	0.0	3.3	1.0	0.0
116	PD	39.3	1.1	4.6	5.4	0.0	380	CMS	-10.2	0.0	3.3	1.7	0.0
117	PD	45.9	0.0	4.7	1.0	0.0	381	CMS	-2.7	0.0	3.3	1.0	0.0
118	PD	3.7	0.5	3.9	2.4	0.0	382	CMS	1.4	0.0	3.4	1.0	0.0
119	PD	-11.0	1.1	4.1	3.9	0.0	383	CMS	12.7	0.0	3.4	1.0	0.0
120	PD	9.2	0.7	4.0	2.9	0.0	384	CMS	-6.9	0.0	3.3	4.3	0.0
121	PD	-70.3	9.0	6.1	8.8	0.0	385	CMS	37.4	0.0	3.3	1.0	0.0
122	PD	-42.7	1.0	5.8	10.0	2.5	386	CMS	12.8	0.0	3.3	1.0	0.0
123	PD	-16.8	1.2	4.4	4.8	0.0	387	CMS	6.4	0.0	3.2	2.1	0.0
124	PD	-5.3	3.7	4.8	5.2	3.1	388	CMS	45.3	0.0	3.3	1.0	0.0
125	PD	14.8	1.8	4.9	5.8	0.0	389	CMS	14.1	0.0	3.2	1.0	0.0
126	PD	78.6	2.1	5.7	5.3	4.6	390	CMS	28.0	0.0	3.3	1.0	0.0

127	PD	-10.6	1.5	5.3	5.3	0.0
128	PD	-29.8	1.3	7.3	11.4	0.0
129	PD	23.5	4.6	4.9	8.7	0.0
130	PD	12.0	0.0	4.1	3.1	0.0
131	PD	45.6	1.6	4.6	4.4	0.0
132	PD	19.5	0.0	8.0	12.7	0.0
133	PD	37.3	0.8	5.0	3.9	0.0
134	PD	78.1	5.9	8.4	6.8	0.0
135	PD	-24.1	1.6	6.0	5.1	0.0
136	PD	-18.5	2.2	4.8	7.6	0.0
137	PD	6.6	1.3	3.3	4.0	0.0
138	PD	-17.9	2.2	4.8	7.5	0.0
139	PD	6.8	0.8	4.1	2.2	0.0
140	PD	-9.9	0.3	3.6	2.8	0.0
141	PD	7.6	0.0	5.4	4.4	0.0
142	PD	-45.2	0.0	5.3	1.0	0.0
143	PD	6.7	0.0	4.7	1.0	0.0
144	PD	14.4	0.6	4.2	3.4	0.0
145	PD	-24.1	0.1	4.3	4.4	0.0
146	PD	23.7	1.5	5.2	5.4	3.8
147	PD	29.3	1.2	5.0	4.5	6.2
148	PD	39.8	1.8	4.6	3.0	1.3
149	PD	51.1	1.4	4.8	3.7	1.3
150	PD	10.1	1.7	4.7	5.4	0.0
151	PD	14.4	0.7	4.3	3.9	0.0
152	PD	-2.5	0.0	5.4	1.0	0.0
153	PD	-0.6	3.6	4.6	6.2	1.7
154	PD	-19.2	0.7	4.7	5.7	0.0
155	PD	17.2	0.4	3.9	2.9	0.6
156	PD	44.9	1.6	4.7	4.8	0.0
157	PD	-11.8	2.7	4.3	6.0	0.0
158	PD	14.0	2.7	6.7	8.5	0.0
159	PD	6.4	1.2	3.9	3.4	0.0
160	PD	49.5	1.6	5.5	5.9	1.4
161	PD	1.1	0.0	4.8	1.0	0.0
162	PD	13.8	0.6	4.4	3.4	3.8
163	PD	-5.6	0.9	4.7	6.4	0.0
164	PD	13.4	1.4	5.3	3.7	0.0
165	PD	46.6	1.7	6.7	7.8	1.7
166	PD	-172.3	0.7	3.8	3.1	0.0
167	PD	20.8	4.9	4.9	5.5	0.0
168	PD	-3.7	4.4	6.7	14.0	0.0
169	PD	22.5	0.8	3.3	2.0	0.0
170	PD	48.5	2.4	5.6	6.9	1.0
171	PD	15.7	1.8	4.0	2.7	0.0
172	PD	57.1	2.1	4.1	2.8	0.0
173	PD	-104.8	0.0	4.8	5.4	0.0
174	PD	16.1	3.2	4.7	4.9	0.0
175	PD	8.3	0.2	4.5	2.0	0.0
176	PD	-4.0	0.0	5.7	1.0	0.0
177	PD	39.5	0.5	5.4	5.1	2.2
178	PD	34.1	3.6	5.2	5.9	0.0
179	PD	55.1	2.6	4.8	3.5	0.0
180	PD	-3.1	0.0	4.9	4.9	0.0
181	PD	50.7	5.0	3.2	6.9	0.0
182	PD	5.5	0.7	6.0	4.3	1.8
183	PD	12.9	0.9	4.3	2.6	0.0
184	PD	-6.9	1.5	4.3	4.4	0.0
185	PD	5.6	0.0	4.0	1.0	0.0
186	PD	19.3	1.3	4.4	4.1	0.0
187	PD	9.4	0.0	4.9	1.0	0.0
188	PD	-14.2	4.0	5.1	5.6	0.0
189	PD	2.2	3.9	4.3	6.2	0.0
190	PD	37.6	2.0	5.2	5.0	0.0
191	PD	-7.4	3.2	6.5	12.8	0.0
192	PD	35.2	0.3	3.8	2.2	0.0
193	PD	11.7	0.7	4.1	3.8	0.0
194	PD	-3.2	2.7	3.8	4.6	0.0
195	PD	54.3	1.6	4.7	3.4	0.0
196	PD	-16.8	11.2	5.4	6.8	0.0
197	PD	-18.8	0.0	5.4	1.0	0.0
198	PD	12.0	1.5	9.4	10.5	0.0
199	PD	-16.9	2.5	5.0	8.3	0.0
200	PD	-4.0	2.0	5.3	5.1	0.0
201	PD	1.8	1.2	4.2	2.6	0.0

391	CMS	11.0	0.0	3.3	1.0	0.0
392	CMS	-73.0	0.0	3.3	1.0	0.0
393	CMS	-26.7	0.0	3.3	2.3	0.0
394	CMS	-29.2	0.0	3.3	1.9	0.0
395	CMS	37.3	0.0	3.3	1.0	0.0
396	CMS	-11.6	0.0	3.3	1.4	0.0
397	CMS	-23.6	0.0	3.3	1.0	0.0
398	CMS	-48.1	0.0	3.3	3.5	0.0
399	CMS	4.3	0.0	3.3	1.0	0.0
400	CMS	-30.8	0.0	3.3	4.3	0.0
401	CMS	-9.3	0.0	3.3	1.2	0.0
402	CMS	-6.8	0.0	3.4	1.2	0.0
403	CMS	-34.3	0.0	3.3	4.4	0.0
404	CMS	2.0	0.0	3.2	2.4	0.0
405	CMS	2.6	0.0	3.3	2.0	0.0
406	CMS	-42.3	0.0	3.3	2.0	0.0
407	CMS	-72.5	0.0	3.3	3.8	0.0
408	CMS	-14.4	0.0	3.2	3.3	0.0
409	CMS	-97.3	0.0	3.3	2.6	0.0
410	CMS	16.2	0.0	3.3	2.7	0.0
411	CMS	48.7	0.0	3.3	1.9	1.9
412	CMS	33.4	0.0	3.3	1.0	0.0
413	CMS	24.6	0.0	3.3	1.0	1.3
414	CMS	-63.6	0.0	3.3	9.1	0.0
415	CMS	18.9	0.0	3.3	1.0	0.0
416	CMS	-21.5	0.0	3.3	1.0	0.0
417	CMS	-7.5	0.0	3.3	3.0	2.4
418	CMS	-19.3	0.0	3.3	4.6	0.0
419	CMS	-12.3	0.0	3.3	1.0	0.0
420	CMS	-18.2	0.0	3.3	1.0	0.0
421	CMS	2.4	0.0	3.2	2.7	0.0
422	CMS	-10.5	0.0	3.3	1.0	0.0
423	CMS	-4.9	0.0	3.3	1.0	0.0
424	CMS	50.1	0.0	3.3	1.0	0.0
425	CMS	15.5	0.0	3.3	1.2	0.0
426	CMS	-17.6	0.0	3.3	1.3	0.0
427	CMS	42.9	0.0	3.3	1.7	0.1
428	CMS	58.1	0.0	3.3	1.0	8.7
429	CMS	-44.2	0.0	3.3	1.0	0.0
430	CMS	-19.2	0.0	3.2	1.0	0.0
431	CMS	-89.8	0.0	3.3	2.0	0.0
432	CMS	34.7	0.0	3.3	1.0	0.0
433	CMS	29.9	0.0	3.3	2.2	0.0
434	CMS	20.3	0.0	3.4	1.0	0.0
435	CMS	8.2	0.0	3.4	1.0	0.0
436	CMS	-4.5	0.0	3.3	1.6	0.0
437	CMS	-4.9	0.0	3.3	1.0	0.0
438	CMS	21.2	0.0	3.3	1.0	2.6
439	CMS	122.7	0.0	3.3	2.9	0.0
440	CMS	29.1	0.0	3.3	6.4	0.0
441	CMS	-18.8	0.0	3.2	1.0	0.0
442	CMS	10.1	0.0	3.3	1.8	0.0
443	CMS	45.5	0.0	3.3	2.7	0.0
444	CMS	-34.5	0.0	3.3	1.0	0.0
445	CMS	103.0	0.0	3.3	1.0	0.0
446	CMS	-149.7	0.0	3.3	1.0	0.0
447	CMS	157.5	0.0	3.2	1.0	0.0
448	CMS	-46.6	0.0	3.3	2.2	0.0
449	CMS	9.5	0.0	3.3	2.7	0.0
450	CMS	-3.8	0.0	3.2	1.0	0.0
451	CMS	-69.3	0.0	3.3	1.0	0.0
452	CMS	1.7	0.0	3.3	1.0	0.0
453	CMS	-30.9	0.0	3.3	1.0	0.0
454	CMS	-6.8	0.0	3.2	5.3	0.0
455	CMS	23.3	0.0	3.3	1.6	0.0
456	CMS	31.0	0.0	3.3	1.0	0.0
457	CMS	44.2	0.0	3.3	1.0	0.0
458	CMS	-25.4	0.0	3.3	2.1	0.0
459	CMS	39.4	0.0	3.3	2.4	0.0
460	CMS	13.3	0.0	3.3	1.0	0.1
461	CMS	86.2	0.0	3.3	1.0	1.2
462	CMS	82.7	0.0	3.3	1.0	0.0
463	CMS	-20.6	0.0	3.3	1.0	0.0
464	CMS	29.9	0.0	3.3	1.4	0.0
465	CMS	-14.9	0.0	3.3	1.0	0.0

202	PD	89.7	7.9	23.7	11.7	0.0
203	PD	33.9	0.0	4.5	1.0	0.0
204	PD	-23.3	2.1	8.9	14.8	0.0
205	PD	-6.8	0.0	6.2	1.0	0.0
206	PD	51.2	1.2	6.6	6.8	0.0
207	PD	22.4	1.2	4.4	3.8	0.0
208	PD	-18.4	0.6	5.4	7.3	0.0
209	PD	55.4	4.9	5.8	7.3	1.9
210	PD	36.6	0.8	4.1	3.3	0.0
211	PD	18.8	0.4	3.9	1.4	0.0
212	PD	21.7	0.0	3.2	1.0	0.0
213	PD	-4.9	2.5	4.6	6.3	0.0
214	PD	-13.2	2.8	5.8	9.6	4.1
215	PD	7.1	1.5	4.5	4.5	0.0
216	PD	3.9	1.8	4.6	5.6	0.0
217	PD	9.3	1.2	4.8	5.7	0.0
218	PD	-49.8	7.3	6.0	11.4	0.0
219	PD	-8.5	0.6	4.7	5.6	0.0
220	PD	-1.0	0.4	4.7	6.1	0.1
221	PD	-2.6	1.9	3.2	5.9	1.1
222	PD	45.3	0.0	10.8	7.3	0.0
223	PD	11.5	2.1	5.7	7.2	1.5
224	PD	-54.5	1.7	3.4	5.9	0.4
225	PD	10.1	2.1	5.1	5.6	0.4
226	PD	9.3	3.2	6.8	12.7	0.0
227	PD	40.1	1.8	4.8	3.6	0.0
228	PD	51.6	1.1	4.2	3.1	0.5
229	PD	-20.0	5.1	5.4	8.3	0.0
230	PD	70.8	2.1	3.8	3.9	1.9
231	PD	34.9	1.2	5.1	5.8	0.0
232	PD	-23.3	4.0	5.4	7.7	0.0
233	PD	68.4	2.1	6.6	4.2	0.0
234	PD	-2.0	3.2	5.0	6.8	0.0
235	PD	41.6	2.4	4.3	3.4	0.0
236	PD	6.1	2.8	6.1	11.0	0.0
237	PD	71.4	1.7	5.9	4.9	0.0
238	PD	36.9	3.4	4.4	4.8	0.0
239	PD	37.0	3.0	4.5	5.5	0.0
240	PD	17.8	0.7	3.7	2.2	0.1
241	PD	51.0	1.2	4.6	6.1	0.0
242	PD	20.6	0.6	4.8	4.2	4.8
243	PD	17.1	0.7	3.9	2.1	2.0
244	PD	-2.2	2.8	6.9	13.5	0.0
245	PD	30.7	0.9	4.2	3.5	6.2
246	PD	24.4	1.4	5.0	2.8	0.0
247	PD	8.7	0.0	3.9	1.0	0.0
248	PD	1.7	1.1	4.3	3.7	0.0
249	PD	-12.1	2.3	3.5	4.2	0.0
250	PD	13.8	1.1	4.4	4.2	0.0
251	PD	-17.7	4.7	5.1	7.8	0.0
252	PD	-14.7	2.1	4.6	4.5	0.0
253	PD	16.0	0.0	5.0	3.9	0.0
254	PD	-17.5	0.4	4.2	4.7	0.0
255	PD	-13.1	1.0	4.9	3.0	0.0
256	PD	-20.9	1.6	4.5	5.3	0.0
257	PD	-19.3	4.8	6.2	13.4	0.0
258	PD	43.7	0.0	5.3	5.1	0.0
259	PD	66.1	2.8	5.3	7.1	0.0
260	PD	3.3	3.4	4.8	6.4	0.0
261	PD	34.5	0.0	6.1	4.5	1.2
262	PD	6.2	1.0	4.4	4.4	0.0
263	PD	16.6	0.4	4.7	5.4	0.0
264	PD	95.5	4.7	3.6	3.0	0.0
466	CMS	52.6	0.0	3.3	2.0	0.0
467	CMS	86.4	0.0	3.2	1.0	0.0
468	CMS	-28.4	0.0	3.3	1.0	0.0
469	CMS	2.9	0.0	3.4	1.8	0.0
470	CMS	73.1	0.0	3.3	1.0	0.0
471	CMS	-91.6	0.0	3.3	1.0	0.0
472	CMS	-41.3	0.0	3.3	1.2	0.0
473	CMS	-37.9	0.0	3.3	2.2	0.0
474	CMS	-60.3	0.0	3.2	1.9	0.0
475	CMS	-48.8	0.0	3.3	1.9	0.0
476	CMS	-41.3	0.0	3.3	2.0	0.0
477	CMS	-52.3	0.0	3.3	1.8	2.6
478	CMS	-61.3	0.0	3.3	4.7	0.0
479	CMS	-74.6	0.0	3.3	1.0	0.0
480	CMS	28.6	0.0	3.3	3.6	0.0
481	CMS	-1.0	0.0	3.3	1.0	0.0
483	CMS	136.6	0.0	3.3	1.0	0.0
485	CMS	43.8	0.0	3.3	1.6	0.0
486	CMS	35.2	0.0	3.3	4.1	0.0
487	CMS	90.5	0.0	3.3	1.2	0.0
488	CMS	-4.4	0.0	3.3	1.0	0.0
489	CMS	-70.5	0.0	3.3	1.5	0.0
490	CMS	136.5	0.0	3.3	1.0	0.0
492	CMS	14.5	0.0	3.3	1.0	1.6
493	CMS	-21.2	0.0	3.3	1.0	0.0
494	CMS	-64.0	0.0	3.3	1.1	0.0
495	CMS	-46.8	0.0	3.3	1.4	0.0
496	CMS	13.6	0.0	3.3	1.0	0.0
497	ILA	150.5	0.0	3.3	1.5	1.9
498	ILA	132.8	0.0	3.3	1.0	2.6
499	ILA	5.4	0.0	3.3	2.6	1.4
500	ILA	118.0	0.0	3.3	1.6	1.6
501	ILA	-10.2	0.0	3.3	2.2	1.2
502	ILA	-19.7	0.0	3.2	2.6	1.2
503	ILA	125.9	0.0	3.3	1.0	1.1
504	ILA	-64.5	0.0	3.3	2.8	1.2
505	ILA	1.2	0.0	3.3	3.0	1.8
506	ILA	-16.5	0.0	3.2	4.6	1.2
507	ILA	13.7	0.0	3.3	5.2	1.2
508	ILA	13.2	0.0	3.2	1.4	1.2
509	ILA	127.0	0.0	3.3	1.8	1.5
510	ILA	32.4	0.0	3.3	1.0	1.0
511	ILA	-22.6	0.0	3.2	5.0	1.2
512	PD	28.0	0.3	4.1	2.0	0.5
513	PD	33.9	0.0	3.6	2.4	0.0
514	PD	1.4	0.0	4.1	1.9	0.0
515	PD	40.1	0.0	5.4	1.0	0.0
516	PD	20.0	0.9	4.0	2.7	0.0
517	PD	-11.0	0.0	3.6	1.1	0.0
518	PD	47.0	0.0	3.5	4.0	0.0
519	PD	17.2	0.5	4.2	1.7	0.0
520	PD	-1.6	0.5	3.7	3.0	0.0
521	PD	89.2	0.0	3.7	1.0	0.0
522	PD	6.9	0.4	4.7	1.8	6.0
523	PD	82.9	0.8	5.5	6.9	0.0
524	PD	32.2	0.0	5.4	1.4	0.0
525	PD	15.5	0.3	5.2	4.3	0.0
527	PD	64.8	0.0	3.5	1.0	0.0

Source: Study simulations

Appendix 13: STATA-tests for biological production data

Overview of STATA t-test for testing differences in the biological production data between the diseases and the control group. The t-tests performed are simple t-tests with two-samples and variances assumed equal.

	Obs	Mean	Std. Err.	Diff[1] Mean	Std. Err	Ha: diff < 0 Pr(T < t)	Ha: diff > 0 Pr(T > t)
Length of production cycle (months)							
Control	857	16.24	.1877				
PD	307	18.73	.2388	2.489	.3378	1.0000	0.0000
ISA	23	16.05	1.188	-.1865	1.303	0.4431	0.5569
CMS	175	17.87	.3712	1.626	.4382	0.9999	0.0001
eFCR (x)							
Control	857	1.2183	.0180				
PD	307	1.4008	.0451	.1824	.0403	1.0000	0.0000
ISA	23	1.6334	.1856	.4150	.1269	0.9994	0.0006
CMS	175	1.2357	.0412	.0174	.0432	0.6565	0.3435
bFCR (x)							
Control	857	1.1345	.0131				
PD	307	1.2150	.0199	.0805	.0246	0.9995	0.0005
ISA	23	1.3619	.1191	.2274	.0919	0.9932	0.0068
CMS	175	1.1336	.0316	-.0008	.0318	0.5112	0.4888
Smolt yield (kg)							
Control	857	3.7672	.0447				
PD	307	3.5721	.0508	-.1950	.0789	0.0068	0.9932
ISA	23	2.7770	.2803	-.9902	.3104	0.0007	0.9993
CMS	175	4.2681	.0960	.5008	.1058	1.0000	0.0000
Full cycle mortaltity (%)							
Control	857	.14227	.0066				
PD	307	.16421	.0063	.0219	.0116	0.9705	0.0295
ISA	23	.28422	.0586	.1419	.0421	0.9996	0.0004
CMS	175	.12009	.0082	.0221	.0147	0.9336	0.0664

1. diff = mean (Disease) - mean (Control)
H0: diff = 0