University of
Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study programme/specialisation: Industrial Economics Project Management Operation and Maintenance	Spring semester, 2020 Open
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Title of master's thesis: *Quantifying the economic impacts of viral disease in Norwegian aquaculture.* Tittel på masteroppgaven: *En empirisk studie av den økonomiske konsekvensen av virussykdommer på laks i norsk oppdrettsnæring.*	
Credits: 30	
Keywords: Salmon, Aquaculture, Viral disease, PD, ISA, Panel data, Regression, Biomass, Growth rate, Sea lice, Cost estimation.	Number of pages: **62** + supplemental material/other **10.** Stavanger, 14.06.2020 date/year

Preface

This master's thesis symbolizes the completion of my education as an Engineer at the University of Stavanger (UiS). It has been both challenging and downright tiresome at times but also extremely fulfilling to write this thesis. Through the process of creating a master's thesis you need to use much of the knowledge you have accumulated through your years as a student. It is at this point that many students are made aware of the practical use of many of their more theoretical subjects, as happened to me. After reading a previously finished master's thesis about Norwegian aquaculture, which also happened to be a very well written and interesting paper, I decided to follow in their footsteps and stuck with the same theme.

Norway has always consisted of fishermen, it started out as a necessity, a way to feed our families. Fisheries in Norway has evolved alongside many other industries, and after the advent of aquaculture as we know it today, Norway has been one of the leading suppliers. As modern society moves forward a need for cleaner and more environmentally friendly food is desired and Norwegian aquaculture is a step in the right direction.

The methodology used in this thesis is based on the work done by Jay Abolofia and James E. Wilen from the university of California. Their research has been critical for the work done in this thesis.

I would also like to announce a special thanks to Ole Kaldheim, one of the authors of the above-mentioned master's thesis, for taking the time to answer any questions about their previous work. Thanks to Merete Fauske at the Norwegian Directory of fisheries for facilitating the transfer of biomass data.

Hope this thesis will bring some insight on the implications of infectious disease in Norwegian aquaculture.

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Stavanger, Norway
June 2020

Abstract

Norway has since the advent of modern aquaculture been leading in the production of farmed Atlantic salmon. The industry has seen a rapid increase in production and combined with an overall increase in salmon price, the industry has been thriving in the second decade of the 2000s. With this rapid growth in mind, several biological challenges have emerged that are threatening the industry’s growth. As the sea pens have gotten larger and denser than ever, the consequences and prevalence of viral disease has increased. Pancreas disease is proven to decrease growth rates and increase production time. decreasing the farmers profit. This study tries to estimate these economic losses due to the reduction in growth rate cause by viral disease. The methodology has previously been used to successfully estimate the economic cost associated with sea lice and sea lice mitigation efforts like mechanical and bath treatments.

The change in biomass growth is estimated using dataset consisting of biophysical variables related to biomass, data on the prevalence and duration of viral diseases and some variables describing lice mitigation actions like mechanical treatments. The dataset consists of monthly data from 2012-2018, from 1041 fish farms stretching the entire length of Norway. Through a panel data estimator, the difference in biological growth rates where estimated and the cost of biomass loss due to viral disease could be computed.

As predicted the prevalence of PD reduced growth rates by a significant amount, an increase in sea water temperature and number of mechanical treatments had a negative impact on biomass growth in combination with PD. An increase in average fish weight reduces the losses associated with PD. An average PD infestation reduce the farmers profit by 15.16 MNOK, 15 % of total revenue lost. Averaging 7.15 NOK/kg of harvested fish.

Innhold

Figure list

Table list

1.Introduction

Norway has since the advent of modern aquaculture held a strong position as an industry leader. Both in terms of production parameters like quality and quantity and in terms of technological advancement. Norway's coastal area is a natural spawning ground for Atlantic salmon which makes it suitable for aquaculture. The long coastline enables larger production quantities without interfering to much with nature. Estimates from the 2019 production puts the production value at 68.1 billion NOK, an increase of 6.7% from 2018 (SSB 2020). The Norwegian aquaculture industry supplies 1.7% of farmed fish worldwide. For context, the whole continent of America, including south and north Amerika, produces around 4.2% of the world consumption (FAO 2018).

Norwegian aquaculture has seen steady growths in the last 20 years but the increase in production quantity has led to an increase in viral disease and sea lice. This is identified as the most restrictive factors in terms of the industry's future growth. As pens get larger and locations denser, both the impact and prevalence of viral diseases and sea lice increased. The response from the industry is at least partially governed by the economic implications of these problems. Abolofia et al. (2017) quantified the cost of lice using regression results from biomass data, later Kaldheim et al. (2019) added to this and included lice treatment options further increasing the accuracy of the results. This thesis intends to further build on their work and a research question regarding viral disease is then presented:

Quantifying the economic cost of viral disease due to biomass loss in Norwegian aquaculture.

The thesis will investigate if the method for quantifying the cost of sea lice developed by Abolofia et al. (2017) can be modified and used for quantifying the cost of viral disease in Norwegian aquaculture. The two notifiable viral diseases *Pancreas Disease* and *Infectious Salmon Anaemia* is the basis for this estimation.

2. Previous research

As a result of many years a leading producer in the aquaculture industry Norway has accumulated a large amount of research on Salmonid aquaculture. Ranging from interference with wildlife and wild salmon stocks to economic estimations done on the industries behalf. In terms of the impact on wildlife several researchers have found strong negative externalities (Christiansen, 2013). Studies on the biology of sea lice, such as (Bricknell et al., 2006) that looked at lice behavior and reproduction traits in different water temperatures. The great cooperation between biologists, economists and industry has resulted in a portfolio of research on the matter.

The quantification of economic loss due to biological factors such as sea lice and viral disease has increased in later years as the problem has increased. An estimation from Iversen et al. (2015/2017) estimated a yearly direct cost of sea lice to be 3 billion NOK and 4.5 billion NOK in 2017. The indirect cost of sea lice, biomass loss etc. was estimated to be 3.04 billion NOK by Abolofia et al. (2017). Costello (2009) estimated the yearly indirect to be 1.39 billion NOK. Lastly Kaldheim et al. (2019) Estimated a yearly cost of 11.2 billion NOK in 2017.

The economic impact of a PD outbreak at a hypothetical fish farm with 500,000 smolt released and a Salmon price at 2010 values would result in a production loss equivalent to 15.6 MNOK (Pettersen et al. 2015). Ruane et al. (2008) has done estimations for the economic implications of PD in Irish aquaculture. The aggregate cost of PD has been estimated to be around 1 billion NOK. (Torrrissen 2008). Later estimation shows aggregated cost of between 1.5 and 5.5 billion NOK (Hagen et al.2016). Henrik Vedeler, the author of a master thesis from the Norwegian School of Economics estimated the cost of PD to be between 1.3 and 2.55 billion NOK in 2017.

There is comparatively less research done on ISA than PD, but some estimations of the overall cost has been done. Cipriano & Miller (2003) estimated in 1999 a yearly cost of 11 million USD. And some estimations for the Chilean ISA infestations have been put between 15 and 25 million NOK.

3. Theory and background knowledge

This chapter will discuss and present some basic information regarding the Norwegian aquaculture industry to better understand the need for quantifying the cost of viral disease in the industry. The rapid expansion over the last decade, at least for Norwegian aquaculture has led to a need for this quantification. Comparative analyses of similar industries and, especially captured fishery will be found in this chapter. The life cycle of salmonid species will be presented and the impact of infectious salmon anemia (ISA) and pancreas disease (PA) will be discussed together with mitigating actions.

3.1 Aquaculture industry

The global aquaculture industry has seen rapid growth in the last decade and as traditional fisheries have seen larger problems regarding overfishing, aquaculture has been deemed a potential fix for this massive problem (FAO, 2018).

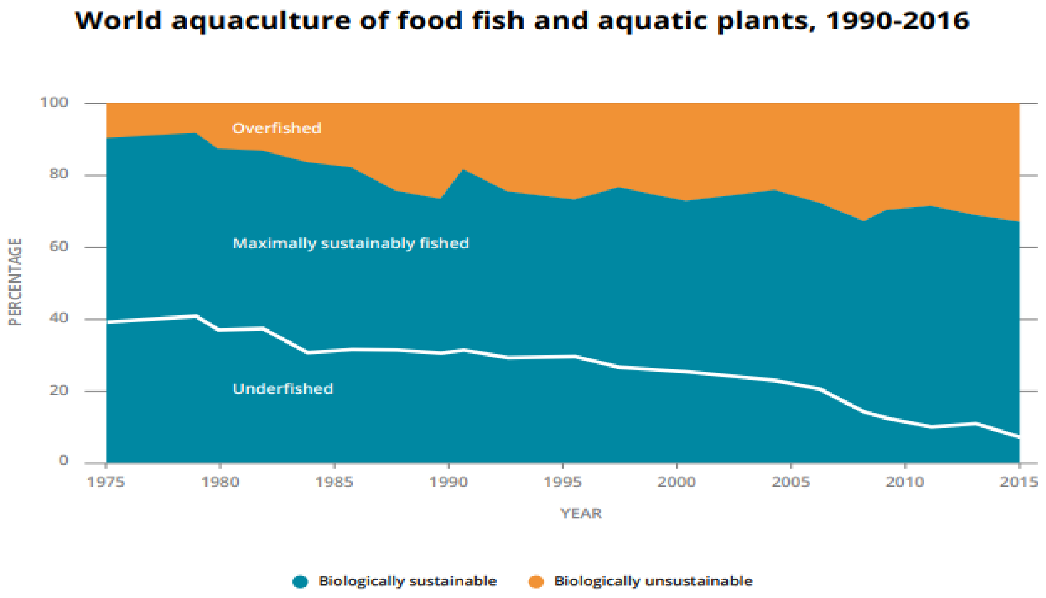


Figure 3.1.1 Global trends in the state of the world's marine fish stocks, 1974–2015 Source: FAO, Sofia report 2018)

As a larger percentage of the world's population rise out of poverty, and the world population increase, the amount of protein needed to keep the population fed is at an all-time high.

Capture production and aquaculture production total almost 200 million tonnes in 2018 and is predicted to increase in the years to come. Ocean farming of Atlantic salmon was started in Norway in the early 70s and started out as freshwater farms for trout, and later developed into the multibillion-dollar industry it is today (Seafood from Norway). After its mainstream rise in the 70s, the aquaculture industry has continued to rise and is closing in on equal production numbers compared to capture production.

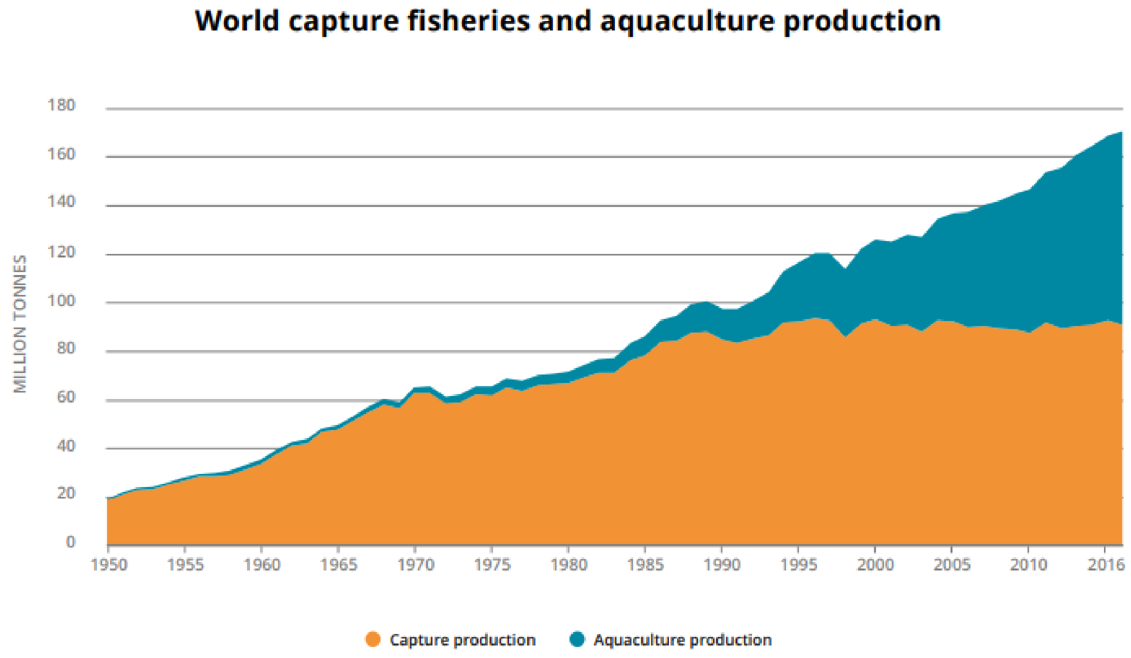
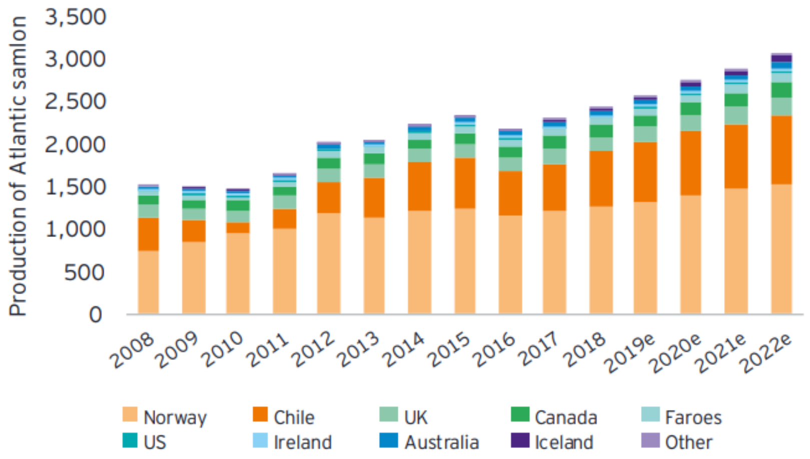


Figure 3.1.2: Total Global Production of Aquaculture and Capture from 1950 to 2016. Source: (FAO, SOFIA report 2018)

Global production of Atlantic salmon reached an all-time high in 2018 and surpassed 2.5 million tons in total. With an annual expected growth rate of 6 % in the upcoming years it is soon expected to surpass 3 million tons (EY. 2019). Norway and Chile are the main producers with UK, Canada and Faroe Island trailing behind in terms of production numbers.

World production of Atlantic salmon (RW 1,000)



Source: Pareto, Kontali 2019

Figure 3.1.2 Global trends in the state of the world's marine fish stocks, 1974–2015 Source: The Norwegian aquaculture analysis 2019).

The most common salmonids that are farmed globally is Atlantic salmon, small trout, large trout, Coho, and Chinook salmon (Pacific species of salmon). But common for all salmonid species is that they are cold-blooded or ectothermic, meaning that they do not self-regulate temperature. Which is great for aquaculture as this internal temperature control requires energy at the expense of growth. This is great for feed conversion ratios (FCR) but limits the areas which can be used for salmonid aquaculture due to seawater temperatures and other natural constraints. The ideal temperature for salmonids range between 8 to 14 degrees Celsius.

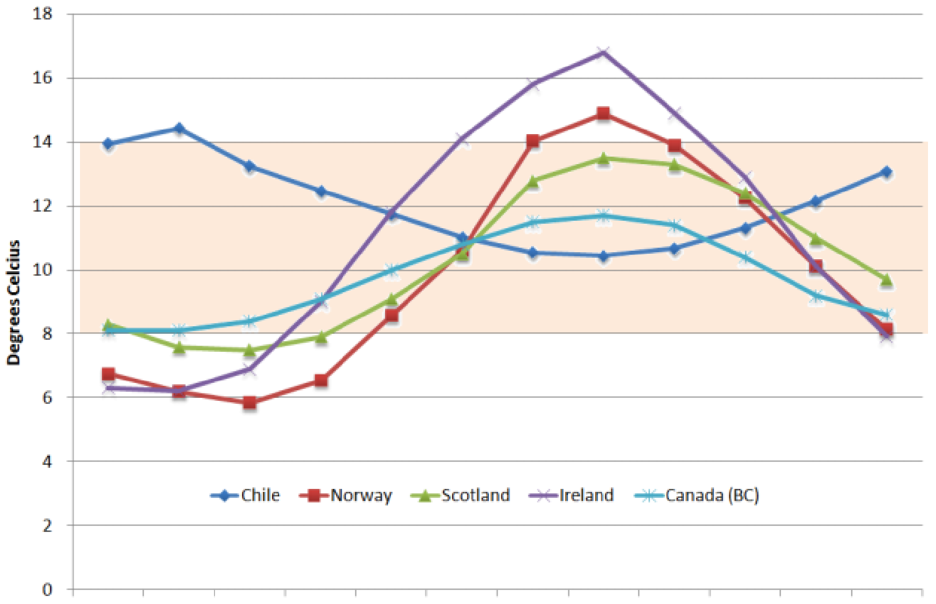


Figure 3.1.3 Sea water temperature. Source: Marine Harvest (2018).

Atlantic salmon aquaculture began in the 1800s to stock up on wild fish for anglers in the UK. Aquaculture as we know it first began in Norway in the 1970s and quickly emerged as an industry with business potential and not just a recreational activity for anglers. The early success of aquaculture of Atlantic salmon in Norway spread in the late part of the 20th century and salmon farms in other suitable areas regarding water temperature and salinity emerged. The success story of Norwegian fish farms encouraged production facilities in Scotland, Farao Islands, Ireland, Canada, North America, Chile, and Australia. Due to intricate biological preconditions, all Atlantic salmon production facilities are between 40-70° north and 40-50° south (Tower 2010).

The early Norwegian success was in part due to the deep sheltered sites available, good hydrographic conditions, a natural, slow maturing grain available in the natural fauna and maybe most important, heavy government support and investment. Compared to UK producers, that faced government resistance and less favorable sea conditions. The combination of Norwegian wild salmon strains, with their late maturity and Scottish strains with high growth rates a suitable strain for fish farming was introduced. This is the same strain that was exported to north America and Chile in the 80s, this was due to the low labor costs and fish meal prices in areas such as Chile. As for Australian farms, they have favorable conditions due to the lack of natural Atlantic salmon in the area, decreasing the impact of fish disease that will be part of the model in the later phases of this thesis. (Tower 2010).

Towards the end of 1980 the global Atlantic salmon Aquaculture industry was facing grave problems as the price plummeted due to increased supply and higher global competition. Diseases amplified this problem and medicine and vaccines that was developed in this period further decreased prices as more fish stock was kept healthy and increased productivity (Aarset and Jacobsen 2004) (Vedeler 2017). And with feed restrictions in the 90s the industry saw slower growth and this agreement was reversed in 2005, when a Maximum Allowed Biomass system replaced the old restrictions. This is apparent as the production between 1992 to 1997 tripled but only increased by 13% between 1999 to 2002.

In 2017 Norway produced over 1.23 million tonnes of Atlantic salmon, this is a rapid increase from the early 1980s as shown in Figure 2.5. The growth for Norwegian aquaculture is expected to stagnate because of biological factors, like sea lice and disease. The government is implementing policies on sea lice quantities and large investments are expected to come in regions such as South America, North America, and the UK (EY 2019). On the other hand, global demand is expected to rise due to increased protein demand because of growing populations and living standards. This shows that the potential for Norwegian aquaculture should the biological factors be diminished is quite large.

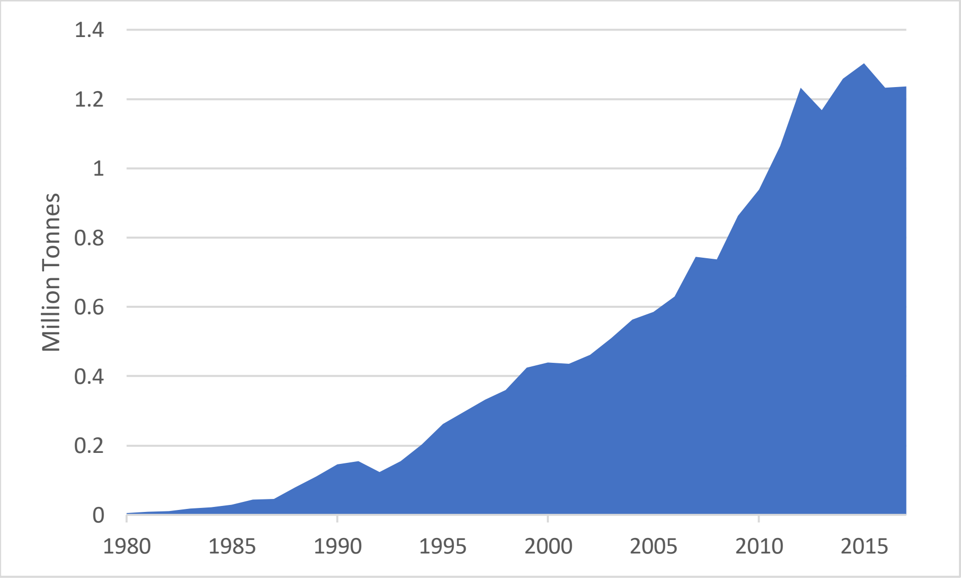


Figure 3.1.5 Norwegian salmon production by year. Source: FAO 2018.

3.1 Production cycle for Atlantic salmon.

Atlantic salmon and many other salmonids like it, are anadromous, meaning they hatch and live for some period in fresh water before they migrate to saltwater. This transformation in fresh water is called smoltification. Wild salmon will return to the river where they were born at the age of between 1-4 years (Vøllestad 2018). Farmed salmons start their life in a very different way from wild salmon, broodstock and roe is produced and hatched, the smoltification process is overseen and then the salmon can be transported to sea water farms. This process will be described in more detail in the following section (Seafish 2012).

Fertilizing egg

During late autumn eggs are taken from a good performing strain of female salmon, transported to the production facility onshore and fertilized by mixing them with milt from a male fish. The fertilized eggs are held in trays with a constant supply of fresh water. Within 2-3 months of incubation the eggs hatch to produce fry (Seafish 2012).

Fry production

After hatching the larvae feed on the yolk-sack for the first period before feeding commences. This is often referred to as one of the most critical stages of salmon production in terms of mortality and many of the fry are not expected to survive to adulthood.

Smoltification

When the fry has reached a size of 100-150 grams, the smoltification process can take place. This is the process were the fishes gill system transform to adapt to saltwater conditions (Marine Harvest 2019). The smoltification process that happens with farmed salmon is notably faster than that found in wild salmon, wild salmon smoltification can take up to 16 months (Kaldheim et al. 2019). The fast tracking of the smoltification process has led to two distinct periods of the year were smolt is released into sea cages, the fall season (Aug-Oct) and spring season (Apr-May). This creates two different biomass scenarios according to when the smolt was released due to sea temperature differences. Which results in different harvesting weights, growth patterns lice infection levels and disease outbreaks. (Abolofia et al. 2017) This has to some extent resulted in a smoother production cycle and can in some cases work as a form of hedge against lice outbreaks and diseases. Increasing robustness and decreasing risk.

Saltwater production

After the smoltification process the smolt is transported the production facilities in salt water and are normally grown to a size of about 4-5 kg before harvesting (Marine harvest 2018). The production cycle various between 12 and 24 months depending on the time of release. The fall release last 16 months on average and the spring release around 20 months (Abolofia et al. 2017). There are many factors that influence production time, the presence of disease outbreaks, sea lice and other parasites increase the production time as the growth rate is hindered. After harvesting the site is fallowed for between 2 and 6 months before the next batch of smolt can be released into the sea at the same location. It is after the smoltification process most of the value is created and most of the capital is expended on the fish. A lot of capital is put into the fish and it is at this stage the fish is most vulnerable to disease outbreaks and parasitic infections and will therefore be the focus of the analyzes later in the thesis.

3.2 Key factors influencing salmon production

This section will discuss some of the key factors influencing the production process post smoltification, meaning the time after the fish has been released into sea pens at the production facility.

Fish growth

As the growth rate of fish directly influences the revenues of the production companies, a lot of effort is put into figuring out the parameters that govern fish growth. A slower growth rate influences the production companies in one of two ways, either the production process is prolonged or the fish weight at harvest is diminished, either way maximizing fish growth is an effective way of boosting revenue. Often, we speak about biotic and abiotic factors influencing fish growth. Biotic factors are factors related to living organisms of an ecosystem. This includes disease like ISA and PD and parasites like sea lice, which are the main biotic factors discussed in this thesis. Abiotic factors are factors that contribute to fish growth that are out of our control, factors that are inherent in the ecosystem and categorized as not living organisms. This includes things like the weather, sea parameters like temperature and salinity, light, time and so on. These are traditionally hard to control as Norwegian aquaculture has used open sea pens as their main production facilities, and the pens are therefor subject to the environment which is out of our control. (Abolofia et al., 2017)

Because of these biotic and abiotic factors, a specially suited breed of Atlantic salmon has been developed to best suit the environment they are grown in while continuously maintaining good quality meat for consumption. The factors discussed above has also led to the development of onshore production facilities even for post smoltification salmon, minimizing both biotic and abiotic factors through isolation.

Government intervention

Norwegian aquaculture, with open sea pens, tend to negatively impact the surrounding ecosystems. Government regulation and control has been implemented in many of the fish producing countries to combat this effect (Norwegian Society for the Conservation of Nature 2020). Large amounts of sewage, salmon escapes and sea lice infestations on the wild salmon population has led to heavy regulation in Norway. This is most often done through controlling standing biomass and/or the density of fish farms in a location. In Norway, the Aquaculture act of 2005 and the Food Safety Act of 2003 are the most important government regulations governing the salmonid industry. Production volumes are determined by the "maximum allowable biomass" or MAB, which is defined as the maximum allowable volume of fish that can be held at any time in a region. This various by location and is mostly determined based on the farms impact on local and global ecosystems, for instance many lice plagued counties have lower MABs than counties with less problems associated with sea lice and disease. Generally, sites have a MAB of between 2,340 and 4,680 tonnes, but this various by location (Marine Harvest, 2018).

As of 2013 new regulations regarding the presence of sea lice on farmed fish were implemented. The allowable amount of adult female lice decreased from 0.5 lice on average during the summer months and 1 lice per fish on average during the winter months, to 0.5 lice per fish during most of the year and 0.2 lice per fish during the wild smolts migration from fresh water to salt water. The 0.2 lice per fish regulation is implemented at different times according to geographical location due to migration patterns in fish according to climate. The frequency of controls was also sharpened in this regulation and depending on the time of year, the fish pens need to be controlled either weekly or biweekly. The amount of fish needed for controls is also dependent on season, and under the smolt migration 20 fish need to be controlled compared to 10 for the rest of the year (Forskrift om lakselusbekjempelse, 2012) (Norwegian Society for the Conservation of Nature 2020).

The ever-increasing threat of sea lice on farmed salmon production led the Norwegian Directory of Fisheries to develop a "traffic sign" system with the intent to decrease, not change or increase the MAB for certain regions in Norway. The Norwegian cost was split in to 13 distinct sones and their local fish farms impact on the local ecosystem was closely monitored. With the constant monitoring in mind, the sones are given a color ranging from red to green, with yellow being the in-between, meaning no change in MAB. Red meaning that a reduction in MAB is required to minimize impact on environment and green meaning an increase in MAB. Both the seabed and water conditions are monitored through B and C tests (Norwegian Directorate of Fisheries, 2019)

Government regulation has made it mandatory to report findings of viral fish disease like PD and ISA. To hinder the spread of these diseases, new regulation was put in two law in 2007. Several disease sones are made throughout Norway to better control for disease outbreaks. Disease outbreaks are isolated, and the surrounding sites are put on surveillance. From 2007 monthly scales samples was mandatory to check for disease, all reporting must be sent to The Norwegian Directory of Fishery for inspection. No direct government regulation is passed on which countermeasures are most suitable, but early disease detection in combination with vaccines show some effect (Norwegian Veterinary Institute 2018)

Feed

Most livestock production needs feed to grow, the conversion of feed to gains in the livestock is often referred to as the feed conversion ratio (FCR). The FCR measures how many units of feed are needed to increase the biomass of the animal by 1 unit (Marine Harvest 2019).Since salmon are coldblooded animals and have an efficient metabolism the FCR is remarkably low for salmon compared to many of their land-dwelling relatives like pork and beef. This makes for increased revenues as the cost of feeding the farmed fish is lower, and it makes salmon one of the most carbon efficient proteins you can eat (Marine Harvest 2019). There are many different types of feed uses specific cases, that be starter feed, transfer feed, grow-out feed, or health feed.

Table 3.3.1 Comparison between different livestock. Source: Marine Harvest 2018

	Salmon	Chicken	Pig	Cattle
Protein retention	31%	21%	18%	15%
Energy retention	23%	20%	14%	27%
Edible yield	68%	46%	52%	41%
FCR	1.1	2.2	3	4-10
Edible meat pr 100 kg feed.	61 kg	21 kg	17 kg	4-10 kg
Carbon footprint kg CO_2/kg meat	2.9 kg	2.7 kg	5.9 kg	30 g

3.4 Atlantic salmon supply and demand.

In the last 50 years the price of many food commodities has seen a steady decline, implying that production growth has outpaced the demand growth. (Brækkan et al. 2014). Following the 2008 financial crisis many commodities have seen dramatic spikes in price, salmon price being one of those (Aasheim et al. 2011). This price spike is hard to track but many see the rapid increase in investment in index-based agricultural futures markets play an important role. The increased investment in these kinds of indexes is contributed to the idea of mass development in countries like China will increase demand for food commodities.

The global farmed salmon market is a highly traded, homogenous product that has seen incredible growth over the last 30 years. Productivity growth in the 70s and 80s saw a drastic decrease in the price of Atlantic salmon and many in the industry felt the impact of decreased prices (Andersen et al 2008). In contrast to this, in recent years, even at increased production numbers the price has increased. Indicating an increase in demand higher than the increase in supply (Øglend 2013). Market expansion in product forms and geographical space is some of the reasons for this increased demand (Asche and Bjørndal 2011). The increased price volatility of atlantic salmon can largely be contributed to the increase in price volatility of input factors and substitute products according to Øglend (2013). Price volatility can also be contributed to the fact that salmon production, like many other food commodities have an inelastic short-term supply. The fish have long production cycles meaning short term adjustments are impossible, the need for planning for future demand is key. This increased volatility does not directly imply price changes, as only supply or demand changes can alter the price directly.

There are two factors that govern supply shifts: You increase the inputs of your production without changing productivity, resulting in higher supply or you increase productivity with the same inputs. As the main input for salmon farms are production facilities, and these are highly regulated and not directly controlled by the producer, the only realistic way to increase supply is to increase productivity. The stagnation in growth indicates that salmon farming has developed into a mature industry and this stagnation is found by several analysis’s (Kumbhakar and Lovell 2000; Coelli et al. 2005). Asche et al. (2013) and Vassdal and Holst (2011). If productivity is slowing down, relaxation of government regulations may be the only way to increase supply in the future.

3.5 Salmon production cost structure.

As a part of the quantification of economic losses due to viral disease some cost inputs from the aquaculture industry is used. This chapter will discuss the salmon industries cost structure and introduce some terminology that is helpful in later analyses. Iversen et. al. (2015/2017) grouped the costs facing salmon aquaculture in to eight categories: Smolt, feed, labor, insurance, other operating costs, harvest and well boat cost and yield loss. The following chapter will take a deeper dive into these costs and how they impact the revenue stream.

Smolt

The cost of smolt is determined mostly by the producer's production process. The efficiency of the smolt producer's production is reflected in the size and price of the smolt. Generally larger smolt is preferred by the fish farms, as this will reduce the accumulated feed cost and decrease mortality in the early stages the fish's sea water life. Transportation of smolt to production facilities are also a factor that determine the cost of acquiring smolt (Iversen et. al 2015). A general trend in Norwegian aquaculture is the tendency to buy larger smolt, this is mostly done to limit time in the sea and has increased from 2016-2018 (Figure 2.5.1).

Figure 3.5.1 Average weight of releases smolt. Source: Iversen et al. 2015.

Feed cost

As the largest contributor in the cost department for salmon farms, the impact of feed prices and feed conversion ratios greatly impacts revenues. In the years between 2010 and 2015 the average feed price increased from 8 NOK/kg to almost 11 NOK/kg, mostly due to cost increased in the manufacturing of feed itself but also due to increased use of feed that are used to combat sea lice and disease outbreaks (Iversen et. al 2015). The feed conversion ratio is dependent upon temperature, water quality and disease outbreaks, meaning a reduction in FCR due to biological factors can cut revenues even more.

Labor cost

As many other industries in resent time, the aquaculture industry has gone through revolutionary changes in terms of labor use. With automation and experience the use of labor has decreased dramatically per unit produced. The use of labor has not increased much since the 1980s, but the production volume has increased many folds. (Asche and Bjørndal, 2011). The automation and productivity increased can only account for part of the decrease in labor per production unit though. Many of the most labor-intensive tasks have gradually been outsourced to other companies. Keeping the total amount of labor required to produce a unit of salmon constant but decreasing the labor for production companies. This increases the demand for third party industries which include companies specializing in sea lice treatment, well boat services and maintenance on pens and nets (Henriksen 2014).

Insurance cost

As all the potential revenue for fish farms are centered around dense pens and small mistakes or biological factors can mean sudden death for the revenue for many fish farms. To hedge against these risks, you can get insurance against many of these potential hazards, these include but are not limited to pollution and damages, algae blooms, escapes, disease outbreaks and sea lice etc. Insurance costs are relatively small in the bigger picture, but potential payouts can be detrimental to the survival of producers. Insurance premiums are calculated monthly and are based on parameters like biomass, average weight and other factors that help represent the state of the fish (Vedeler 2017),

Other operating costs.

Collective term for many other costs associated with production, most often include maintenance, machinery, and fish health costs. This can be the accusation of new machinery, maintenance on machinery etc. Most notable is fish health, both disease outbreaks and sea lice treatments are costly for producers (Iversen et.al 2015).

Harvesting and wellboat transportation.

At harvesting times well boats are used to transport fish to its final slaughtering facility. The cost associated with this transport and other uses of well boats increases cost for the producers. The cost is greatly affected by distanced traveled and capacity usage. Many producers hire extra capacity to reduce cost under normal operating times. Hedging against some of the peaks by out-sourcing (Vedeler 2017).

Yield loss

Every production process will have some sort of loss associated with it, meat scraps at the butcher etc. In the aquaculture industry yield loss is often described as the discrepancy between standing biomass, fish weight in the pens, and the marketable fish weight, gutted weight equivalent. Since farmers mostly sell their fish by gutted weight (GWE), meaning blood and offal has been removed, the yield loss for fish farms averages out at around 16% (Marine harvest 2018).

Financial cost

The financial and interest cost of each company is a result of the economic state of the producer and can vary dramatically. The amount of debt, interest rate and creditors all play a part in the financial costs of the company. Financial costs have followed the general trend in the industry and has decreased from 4.3 % of income in 1995 to 1.2 % in 2017 (Iversen et al. 2017).

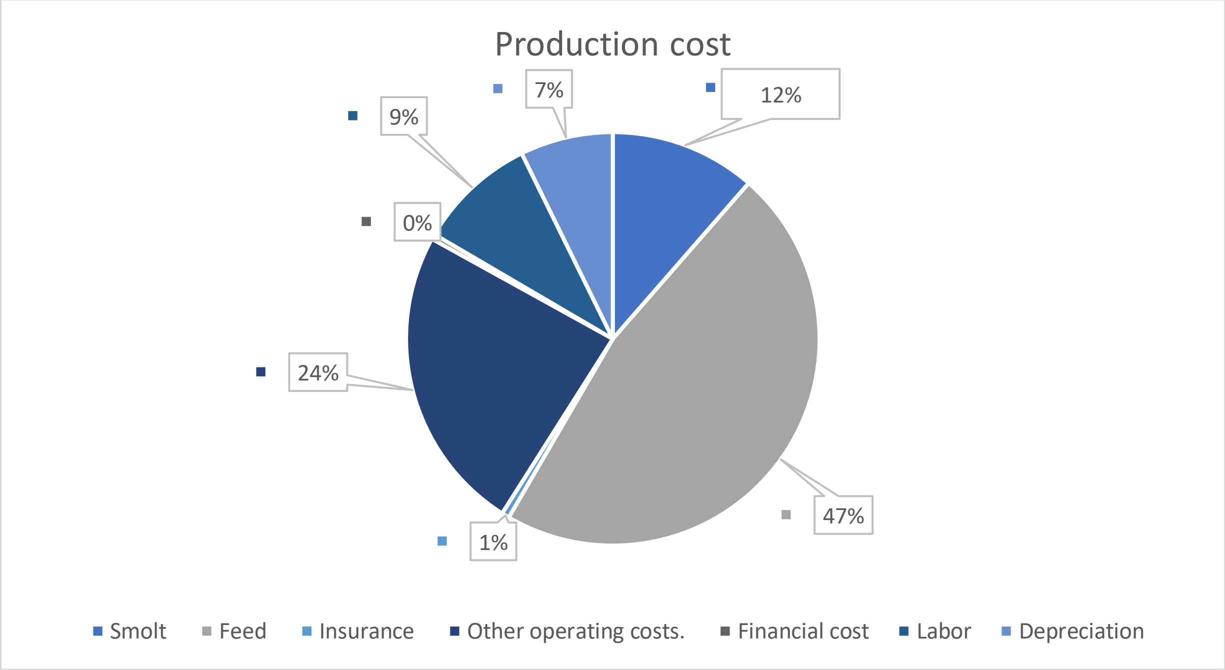


Figure 3.5.2 Production cost as percentage. Source: Iversen et al. 2015.

3.6 Biological challenges.

Aquaculture is a biological process and suspect to diseases and parasites, this is at the utmost concern for farmers as these diseases cause loss of fish. This loss manifests itself as both mortality and loss of biomass due to diminished growth rates. As this is one of the most impactful ways for fish farmers to increase their revenues and for governments to decrease the impact of local wildlife, heavy measures are taken to mitigate the effect of diseases and parasites like sea lice. While the 2018 Norwegian Veterinary Institute analyses appear to indicate a slight improvement to the mortality levels compared to earlier years, the overall mortality rate is to large and large regional differenced exist. (Norwegian Veterinary Institute 2018.). Some of the fish dense areas like Rogaland and Hordaland show a positive trend regarding mortality. 53 million fish did not reach slaughter in 2016 and mortality accounts 87,2 % of this loss.

The governing body authorized to deal with disease prevention and control is the Norwegian Food Safety Authority (NSFA) The NFSA has full authority to mandate premature slaughter, issue fines and control the MAB – allowances as needed to maintain wellbeing for farmed fish and local wildlife.

Diseases are either categorized as listed or not listed, based on criteria set by the NSFA. The main point to take away from this listing is that listed disease are subject to regulation by the authorities and the aim is to eradicate these diseases. The listed diseases are categorized in 3 different lists, with regards to their origin. List 2 disease are disease that do not originate in Norway but are not considered exotic as they are found throughout Europe (Norwegian Veterinary Institute 2018.).

Table 3.6.1 Overview of list 2 and 3 diseases with number of confirmed outbreaks. Figures are based on Norwegian Veterinary Institute data.

Disease	List	2011	2012	2013	2014	2015
ISA	2	1	2	10	20	15
VHS	2	0	0	0	0	0
PD	3	89	137	200	142	137
Furunculosis	3	0	0	0	1	N/A
BKD	3	3	2	2	0	N/A

The use of chemical treatment has since the 70s been the main weapon for dealing with sea lice and frequent treatment has led to the development of resistance to the chemotherapeutants used in chemical treatment. Many of the non-medicinal treatments lead to stress and physical strain for the fish which increase mortality. This is particularly true for fish with other infectious diseases, therefor the combination of sea lice and infectious disease will be analyzed further. The two main disease that will be analyzed in this thesis in addition to sea lice, is PD and ISA as these are the notifiable disease that the fish farms are required to report the authorities (Norwegian Veterinary Institute 2018.). The diseases that are not directly connected to the analyses will non the less be discussed in this chapter as they represent a large cost to the fish farms. The reasoning behind their exclusion is merely the fact that attaining data for these diseases is much harder and require an inexpedient amount of work.

Bacterial diseases

Antibiotics have revolutionized treatment of bacterial diseases in farmed salmon much like what it has done to humans. The consumption of antibiotics has been used as a good indicator for bacterial infections in farmed salmon. The advent of vaccines against Coldwater Vibrosis and Furunculosis in the late 80s and early 90s drastically cut the use of antibiotics and it stayed relatively low ever since. In 2015 and 2016, antibiotic consumption was around 200/300 kg and increased to 900 kg in 2018. 13 antibiotic treatments where issued for sea-farmed salmon in 2018 and 9 for freshwater. These treatments were a response to Moritella Viscosa infections in saltwater salmon and Yersinia Ruckeri infections in freshwater, the remaining cases were categorized as “general bacterial infections”. Bacterial infections continue being a rather small problem in Norwegian salmon farming and is categorized as under control (Norwegian Veterinary Institute 2018.).

Parasitic diseases

Sea lice represents the greatest biological challenge facing salmonid aquaculture and has for a long time. There are two different types of sea lice depending on latitude, *Lepeophterius salmonis* which occurs in the northern hemisphere and *Caligus rogercresseyi* which is native to the southern hemisphere. Parasitic sea lice are a naturally occurring parasite that feeds off salmonid species like sea trout, rainbow trout and salmon. Due to the inherent low density of wild salmonids in the sea, sea lice have evolved to rapidly reproduce when a fresh host is found. The density of wild salmon has through history been low enough to not impose a large threat to wild salmon populations. As farmed salmon became more prominent the rapid reproducing lice can wreak havoc on both farmed and wild salmon if left alone. (Norwegian Veterinary Institute 2018.).

Sea lice, or salmon lice as they are often called, feed off the skin, blood and tissue of salmonid creatures and can greatly weaken the fish and increase the chances of viral and yeast infections. It is also proven through analyzes of biomass data that presence of sea lice decreases the biological growth rate of farmed salmonids, directly decreasing profits for the farmers.

Life stages of sea lice

The life cycle of sea lice can be divided into 10 separate stages, three free-swimming states were the parasite are drifting through open waters looking for a suitable host, four parasitic stages were the lice have attached itself to a suitable host and three mobile stages were they feed upon the host and reach maturity. The parasite attaches to a host via a prehensile antenna, maxilipeds and later through a more durable frontal filament. The mobile lice represent the greatest threat to salmonids due to their size and reproducing capabilities. Adult female lice can constantly reproduce through egg strings that they continuously detach and reproduce. One of these egg strings can contain over 1000 eggs, and with the density of farms seen in Norway in the 2000s, rapid reproduction is possible. One adult female lice can reproduce 6-11 broods within its seven-month life span. (Costello 2006).

Figure 3.6.14 Adult female lice with egg string(top), Adult female lice (mid), Attached lice (bottom). Source: (Bjørkan 2009)

Lice treatments options

In this section the lice treatments that have the largest implication on fish health will be discussed as it is hypothesized that some of the treatments can increase the consequences of the viral diseases that are part of the analyzes in this thesis. The reasoning behind this will be discussed in the respective parts.

In-Feed treatments

In-feed treatments refers the treatment of sea lice either by strengthening the salmonid creature and increasing its resilience to the consequences of sea lice or by medical treatment of the sea lice itself. Decreasing the effect of sea lice or as a delousing agent. The treatments options can make it harder for sea lice to attach through agents that increase the outer layer of mucus on the fish, or by decreasing the inflammatory response of the fish (MSD animal health 2012). The mortality rates of in-feed treatments are generally low, as they are strictly regulated and require strict regulation to use and develop. In-feed treatments are generally more efficient for smaller fish, as the overall mortality rate is higher, and they are often more prone to lethal amounts of lice at the earlier stages. The fish is often starved for periods up to one week before treatment, which in terms of commercial farming results in reduced growth rates and has a cost associated with it. But compared to more complicated delousing treatments the cost is generally low and is largely due to the increased cost of medical feed. The cost is most comprised of the difference in cost between ordinary feed and the feed used for treatments.

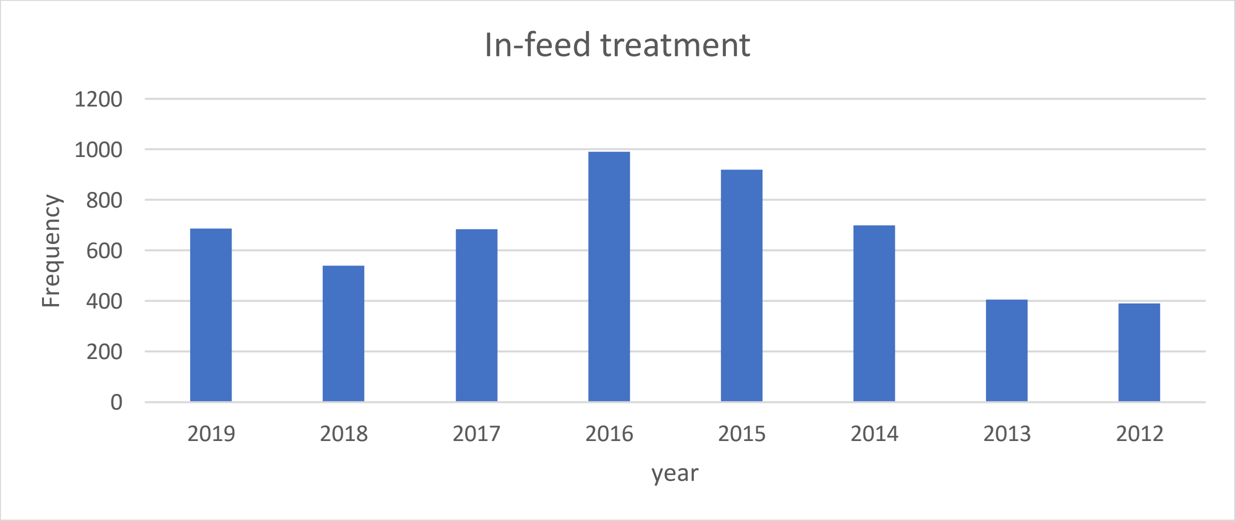


Figure 3.6.2 Frequency of medical treatments through feed. Source: (Barentswatch 2020).

Bath treatment

Bath treatment is another form of medicinal treatment, but it differs from in-feed treatment in the way it is administered. The fish is isolated from the environment often by tarp or well-boat and the chemical treatment is administered through the water surrounding the fish. Many of the chemicals used are like the ones used in-feed and others are only usable through batch treatments. The use of batch treatments has diminished in later years due to resistance to treatment in fish (Emily Osterloff 2020). It has also been indicated that bath treatments have negatively impacted growth rates. The treatment requires high amounts of resources, with high vessel, labor, and treatments costs. It has fallen out of favor and more modern treatments are both more effective and have lower cost.

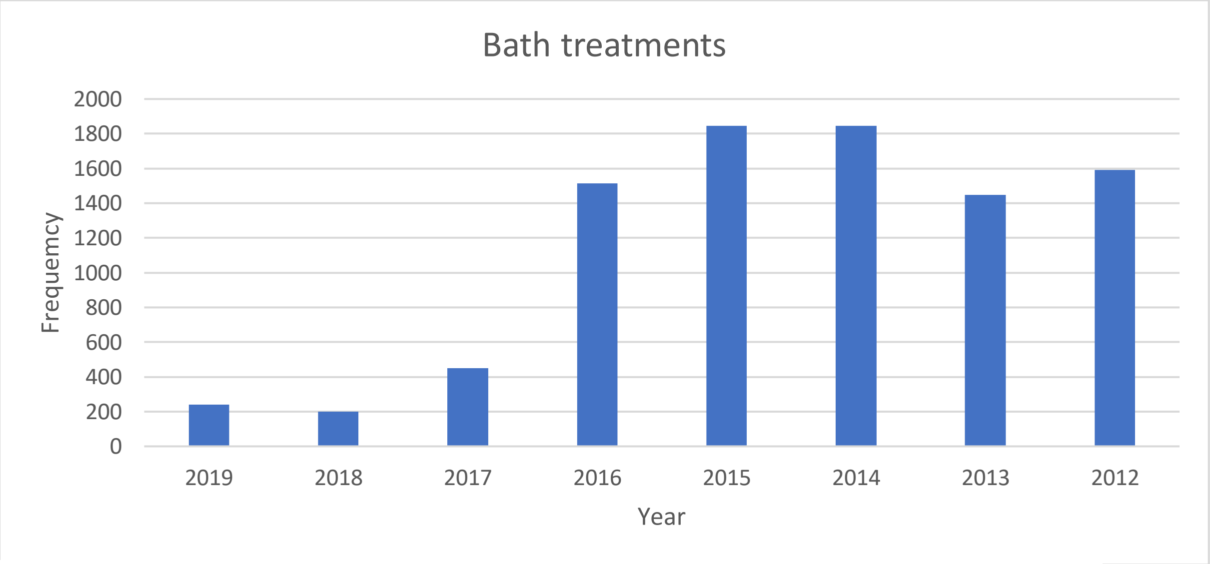


Figure 3.6.3 Frequency of batch treatments. Source: (Barentswatch 2020.)

Mechanical treatment

In recent years, as other treatment options have been phased out, mechanical treatments have emerged as a non-chemical option with high rates of success. Mechanical treatment covers all non-chemical treatments processes, but the most common treatments are thermal, flushing or brushing. Sea lice have low resistance to a sudden change in temperature, this is taken advantage of in modern delousing systems. The salmon is taken through a batch of lukewarm water that kills the lice and returns the fish lice free. Flushers use water jets to remove lice from the fish, they are often passed through a pipe fitted on well-boats or other devices near the pens and are released after the jet has ridded them of sea lice. Brushers use a similar technique but instead of water jets, the louse are pushed of by physical contact with a suitable material (GSI 2020).

Through regression analyses it has been determined that mechanical treatments have a negative impact on biological fish growth and in turn impose a negative effect on revenue for the industry (Kaldheim et al. 2019). The mechanical treatment can induce a stress response in the fish making it more vulnerable to heart disease like cardiomyopathy syndrome (CMS), reduce growth rates and increase mortality (Norwegian Veterinary Institute, 2018).

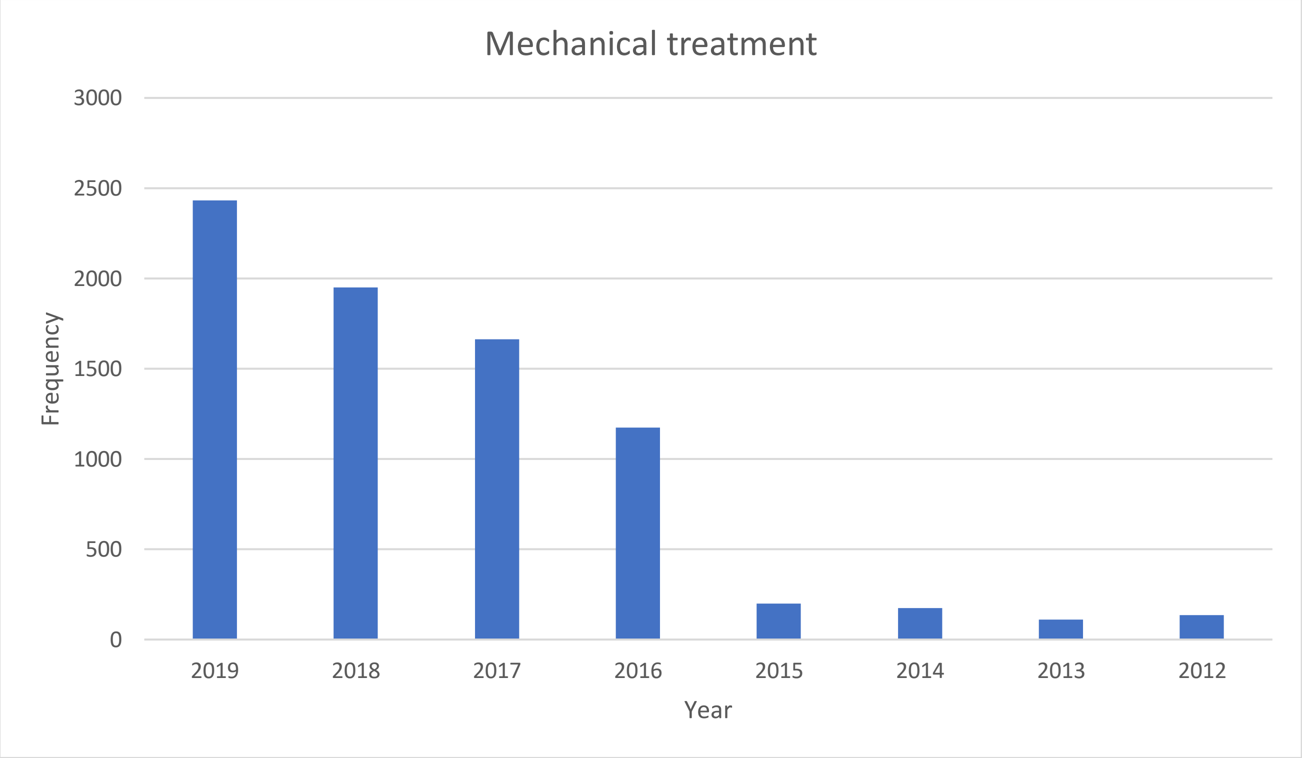


Figure 3.6.4 Frequency of mechanical treatments. Source. (Barentswatch 2020).

Cleaner fish

Cleaner fish are used to in fish pens to decrease the number of lice on fish. The cleaner fish, often fish of the “wrasse” family, live in the sea pens and eat sea lice off the salmonids. While both medicinal and mechanical treatments have drawbacks with regards to mortality and growth rate on salmonids, the use of cleaner fish have little negative impact on the farmed fish. The use of cleaner fish has therefor increased in modern times as more knowledge has been made on the implications of other treatments options, with reports as high as 78% utilization rate in Norwegian farms (Marine Harvest 2018). Which cleaner fish to use is determined by environmental factors like current and temperature, but the most common one by far is lumpfish, accounting for 55% of cleaner fish as of 2017. 5-15 cleaner fish is used per 100 salmonids, and their wellbeing greatly affects their ability to consume sea lice. It is therefore in the farmers best interest to keep the cleaner fish healthy and thriving to increase efficiency (Misund 2017).

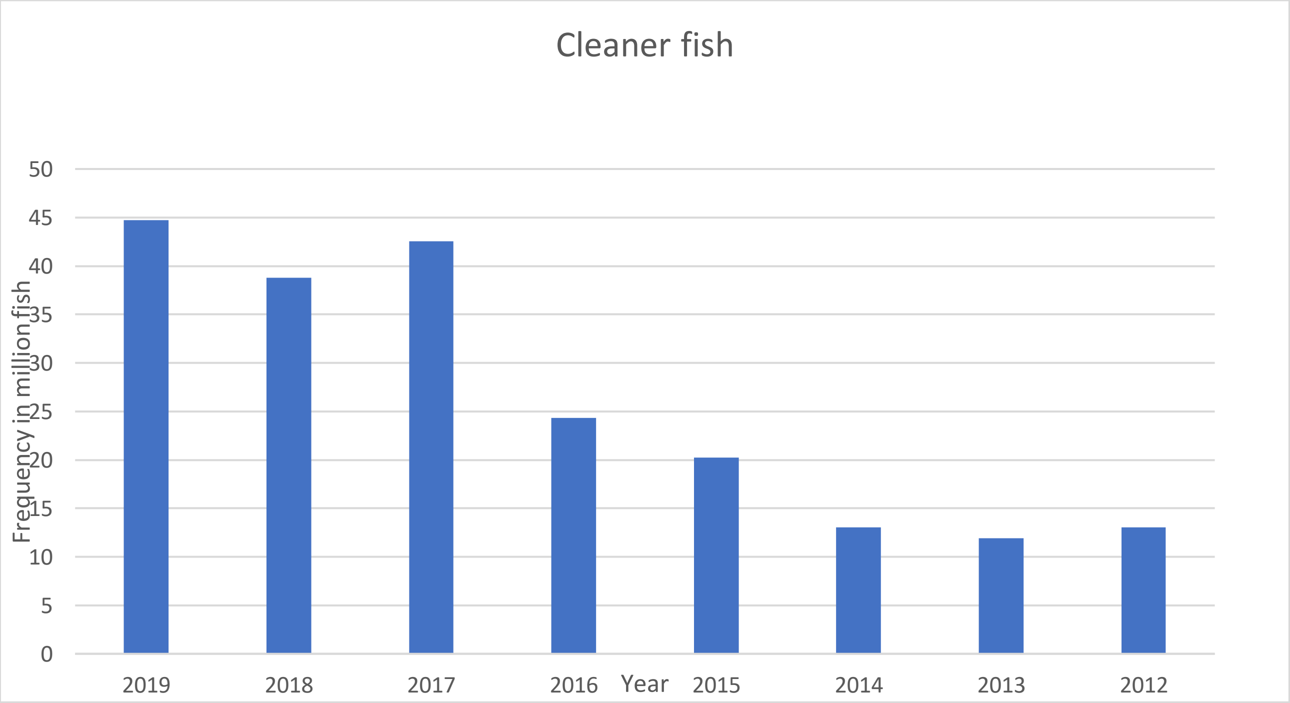


Figure 5: Amount of cleaner fish released in millions. Source. (Barentswatch 2020).

Viral diseases

The third type of disease that affect salmonid creatures in the aquaculture industry is viral diseases. The viral diseases are second only to parasitic sea lice in terms negative health consequences for salmon. It is therefore hypothesized that the viral disease has a high cost associated with them (Norwegian Veterinary Institute 2018.).For the first time in 2018 CMS was deemed the most important viral disease to combat, with PD and ISA being a constant threat.

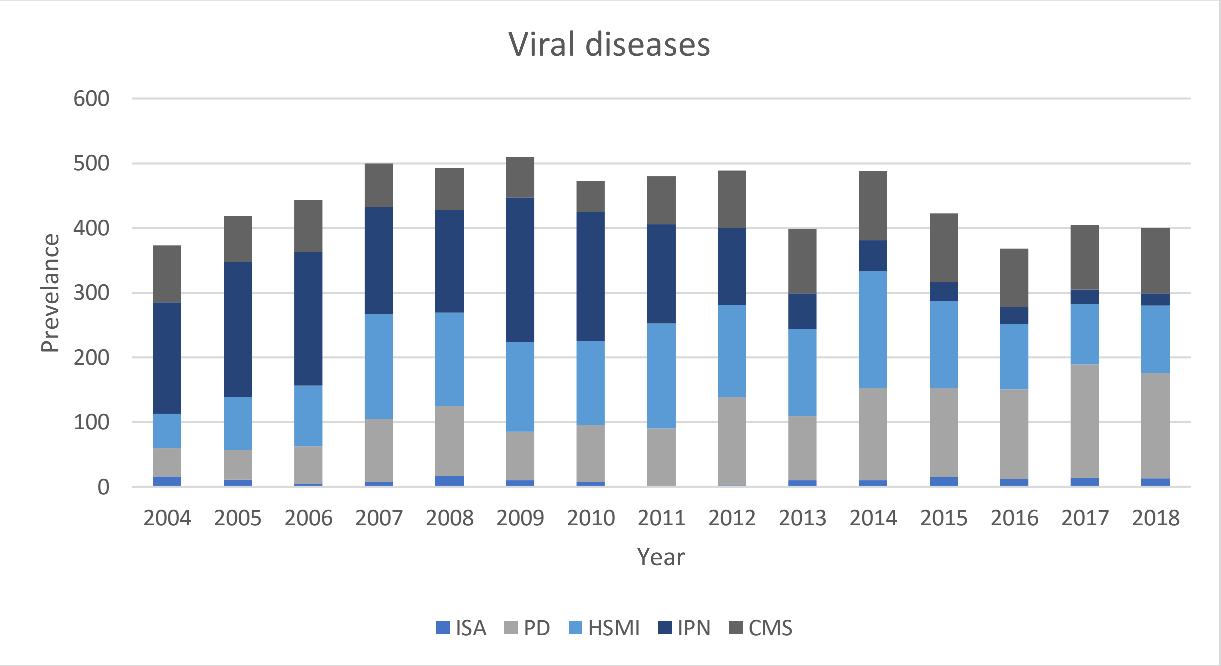


Figure 3.6.6: Prevalence of various viral diseases in farmed salmonids during the period 2001-2018. Source: (Norwegian Veterinary Institute 2018.).

Pancreas disease (PD).

PD is an important and serious viral disease that attack salmonid creatures in the sea, it is caused by the salmonid alphavirus (SAV). Diseased fish show extensive pathological changes in the pancreas and inflammation in the heart and skeletal musculature. Currently there are two PD epidemics in Norway, one subtype, the SAV3 virus, is widespread in western Norway. It was introduced to Norwegian aquaculture in the early 2000s and was first discovered in the Bergen area west in Norway. The introduction of a new subtype, SAV2 in 2010. Nearly all the cases of SAC3 PD occurred south of Stadt, while nearly all SAV2 cases are found North of Møre and Romsdalen. SAV3 is generally considered the most critical one with mortality levels ranging from low to moderate, as for SAV2, it is generally classified as low but isolated cases of higher mortality has been reported. SAV2 Leads to low feed conversion ratios, leading to increased production cycles and may lead to a lower quality result resulting in lower prices.

PD is a notifiable disease, meaning that every aquacultural location must report data on outbreaks weekly. It is also heavily regulated and attempts to eradicate the disease north of Trøndelag has been made. These exclusion zones have not eradicated the disease completely, but it remains a smaller problem in the North of Norway. Steps have been made to both monitor and take quicker action against the disease in pens, transportation measures and rapid control have resulted in lower infection rates. Especially the monitoring and checking of smolt and small fish have resulted in lower biomass losses and a lessened the economic burden. The quick eradication of infected young fish has also reduced the spread of the disease, both locally and regionally (Norwegian Veterinary Institute 2018.).

Commercial vaccines against PD are available and are used to great extent in western Norway. The vaccines are less widely used in Trøndelag. The effect of the vaccines is debatable, and the effect is much lower than that seen on bacterial infections like furunculosis. It is however proven to reduce the number of outbreaks and have shown signs of reducing mortalities in infected areas.

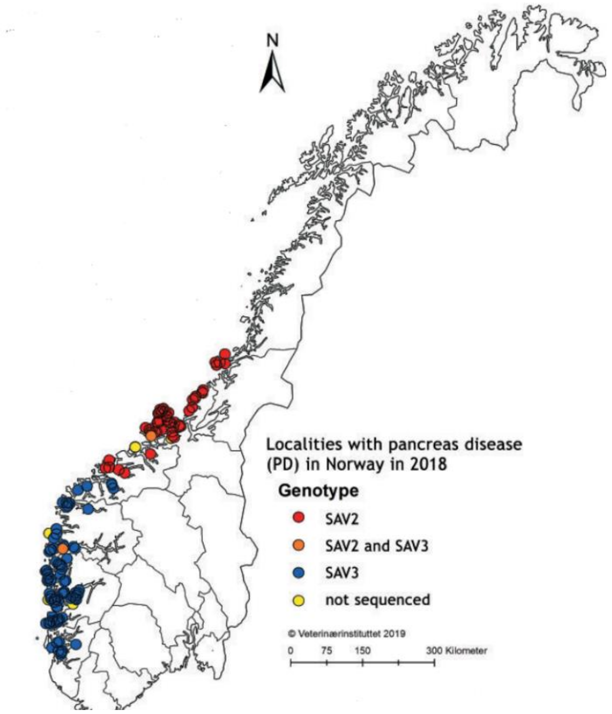


Figure 3.6.76: Map of new localities with pancreas disease (PD) in Norway in 2018 caused by sub-types SAV2 and SAV3. Source: (Norwegian Veterinary Institute 2018.).

Infectious salmon anemia (ISA)

Infectious salmon anemia is a viral disease caused by the infectious salmon anemia vis (ISAV). Natural outbreaks of ISA have been found in farmed Atlantic salmon and is a viral disease that primarily attacks blood vessel. The main findings in dead fish are the lack of red blood cells, also called anemia, various signs of circulatory disturbances, blood vessel damage including a fluid filled abdomen, bleeding in the eyes, skin, organs and necrosis. One of the scary facts of ISA is that infected fish can go extended periods of time without any symptoms, spreading the disease before it is noticed. In such cases it may be extremely difficult to identify the infection before it has spread to the entire location. Mortalities are generally low, hovering between 0.05-0.1 % per day but it is still considered a large economic burden since it can have implications on biomass growth (Norwegian Veterinary Institute 2018.).

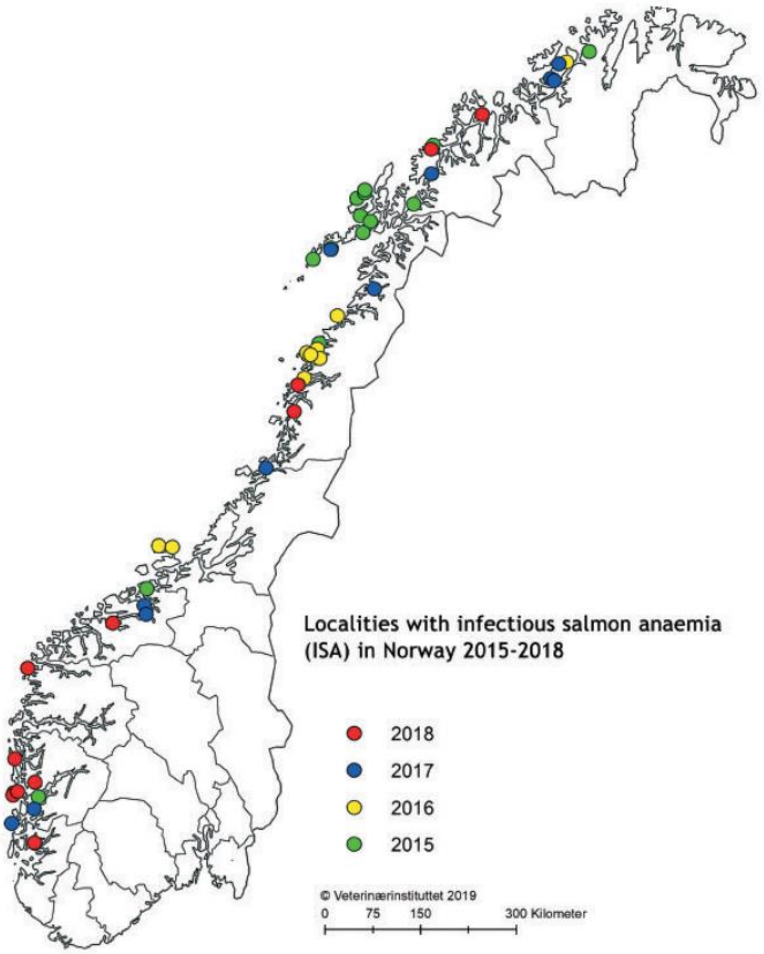


Figure 3.6.8 Map of ISA cases registered in Norway between 2015 and 2018. Source: (Norwegian Veterinary Institute 2018.).

Infectious pancreatic necrosis (IPN)

IPN is a viral disease that unlike many of the other diseases attack primarily farmed salmon. The virus originates from the genus Aquabirnaviridae in the family Birnaviridae. A significant proportion of infected fish develop a lifelong persistent infection, depending on strain and severity. Juvenile fish and smolt seem to be the groups most at risk of serious infection. It is hard to estimate a single mortality rate as it various from strain to strain. Some strains can cause negligible mortality rates and other can be upwards of 90%. In addition to strain variation, large variations in climate and ecological variables differentiate different outbreaks in terms of mortality. In 2018 18 locations had IPN virus strains identified, that is down from over 140 in 2010, this points in the right direction and the disease is no were close to as prominent as it once was (Norwegian Veterinary Institute 2018.).

Heart and skeletal muscle inflammation (HSMI)

HSMI is a very common infection found in salmonid creatures, it can be found in rainbow trout in fresh water and in salmonids in salt water. In salt water the disease is most common in the first year of production but can occur in other stages of production as well. The disease mostly effects the heart, but red skeletal musculature can also be relatively common in salmon with HSMI. Mortality for HSMI various greatly and is correlated with how the fish is handled when infected, stressful treatment and handling of the fish can lead to higher mortality rates. Salmon mortalities are often connected to signs of circulatory disturbances (Norwegian Veterinary Institute 2018.).

Cardiomyopathy syndrome (CMS).

CMS is a very serious cardiac complaint affecting sea farmed salmon all over Europe, it has been found in Norway, Scotland, and the Farao Islands. It was first discovered in Norway in 1985 but has since spread to various fish farms around Europe. Typically, fish are infected in their second year at sea, but for some reason the numbers effecting younger fish are at a all-time high and rising. For some ecological reasons, the autumn released smolt have twice as many reported cases of CMS as the spring release. Autopsy of deceased fish often show inflammatory changes in the inner spongious parts of the atrium and ventricles, while the most compact muscles around the heart seem unaffected. The diseases result in pathological changes like PD and HMSI, but mortalities because of CMS is rarely found. In contrast to many of the other diseases there is no government program for prevention of CMS, which might change in the upcoming years as CMS has become a larger threat. The reasoning behind this increased fear of CMS is the implication CMS has in combination with many of the delousing treatments that puts unnecessary stress on the fish. The combination of CMS and mechanical sea lice treatments might increase mortalities (Norwegian Veterinary Institute 2018.).

4. Data

To be able to perform a regression analyses on biomass losses, a large dataset consisting of biomass data, biophysical variables, lice counts, disease states and treatment options must be acquired. Norway has very strict regulation on the collection of data from fish farms, and it has been mandatory to collect and release data on biomass, lice and the notifiable diseases PD and ISA for some time. This results in very detailed data from across the whole industry for an extended period. The data on lice, lice treatment, disease and disease treatment have been gathered from Barentswatch. Barentswatch is a research site dedicated to collect, develop, and share information about Norwegian coastal and marine areas, they have many of the country’s leading research institutions on their side and has very large and trustworthy database. (Barentswatch 2020). The biomass and biophysical data come from the Norwegian directory of fishery that store data gathered from aquaculture locations all over the country, the data is reported monthly farm by farm. This information however is branded sensitive and is therefore not available to the public. To access this information, you must fill out a form and state your intentions and research purpose. Upon acceptance the school must sign a confidentiality agreement and the data is downloadable.

The dataset consists of 84 monthly reports spanning from January 2012 to December 2018, of all salmon location currently operating in offshore facilities. 1041 unique locations are accounted for, ranging from full data coverage to sporadic coverage, depending on situation and omission criteria. 43,587 non-zero biomass observations are present with accompanying lice and disease statistics. A detailed description of all variables can be found in Table 4. 1. There are 5,887 monthly reports for the viral disease PD and 172 reported cases of ISA. The average number adult female lice are 0.175 with a standard deviation of 0.369. This is well below the maximum allowable amount, but accounting for regional lice attacks with much higher infestation levels the problem is still there. The average lice levels have dropped by 0.05 adult female lice per fish compared with Kaldheim et al. (2019). The average harvested fish weight is 4.91 kg with a standard deviation of 1.94, this is on par with the readings from Kaldheim et al. (2019). The average fish weight is 2,248 kg compared to 2.31 kg Abolofia et al. (2017) and 2.24 kg Kaldheim et.al (2019). The standing biomass is 1,250,00 kg which follows the increase observed by Kaldheim et.al (2019).

Following research from both Abolofia et al. (2017), Jansen et al. (2012) and Kaldheim et al. (2019), I have grouped all farms in 1 out of 3 regions, north, central, and south by latitude. This is used to report special differences as different parts of the country have different lice and disease situations. All farms north of 67 ° North are categorized as North, between 62° and 35 minutes and 67 ° North are classified as part of the central region and everything south of 62 ° and 35 minutes are categorized as belonging to the Southern region. 25,6 % of observations are from the Northern region, 29,6 % of the observations are from the central region and 44,74 % of the observations are from the Southern region. Figure 4.3 provides an overview of the geographical sones.

The total amount of fish released each month is a measure of how many fish are removed/sold of two other locations or for some other reason is removed. This is not accounted for in any of the other variables such as harvesting of misc. losses. The average amount of removed fish is 260,707 fish with 2,116 non-zero observations, this differs greatly from the results Kaldheim et al. (2019) presents and upon further investigation I have reason to believe that they have used the numbers for withdrawal at slaughter which is a datapoint for how many fish are thrown away from slaughter because of misc. causes.

Table 4.1: Summary statistics 2012-2017.

Variable	**Obs**	**Mean**	**Std.Dev.**	**Min**	**Max**
Smolt released.	3825	446333,7	330380.4	428	2370451
Released fish	5,528	411397.1	338572	50	2370451
Number of fish	43587	696000	473000	0	3480000
Biomass (kg)	43587	1250000	1150000	-1242.85	1.05e+07
Average fish weight (kg)	43587	2.248	2.029	-1.855	20.142
Feeduse (tonnes)	43587	239.539	219.297	0	3564.932
Fish mortalities	43353	6303.055	15030.71	1	834000
Fish escapes	53	17549.53	28369.07	1	123000
Misc. losses	13819	1156.241	18077.17	-147000	739000
Amount of harvested fish	9997	143000	126000	1	1420000
Harvested biomass (kg)	9995	682000	609000	3	5200000
Fish removals	2116	261000	306000	87	2350000
Average harvest weight (kg)	9995	4.914	1.941	-102.518	38.127
Adult female lice	43587	.175	.369	0	17.58
Mobile lice	43587	.772	1.374	0	58.158
Total amount of lice	43562	.933	1.5	0	19.7
Temperature (°C)	43463	9.157	3.51	2.04	21
Number of cleaner fish released	6450	24202.43	26681.19	1	398000
Number of bath treatments	43587	.182	.585	0	10
Number of mechanical treatments	43587	.121	.434	0	6
ILA	43587	.004	.063	0	1
PD	43587	.135	.342	0	1
north	43587	.259	.438	0	1
south	43587	.451	.498	0	1
central	43587	.29	.454	0	1
ISA (dummy)	172	1	0	1	1
PD (dummy)	5,887	1	0	1	1
Salmon (dummy	43587	.933	.249	0	1
Rainbow trout (dummy)	43587	.067	.249	0	1

Table 4.2 Description of summary statistics.

Variable	**Description**
Smolt released.	Smolt released by the end of each month
Released fish	Released fish that have been transferred of bought by the end of each month.
Number of fish	Total number of fish in the pens at the end of each month
Biomass (kg)	Standing biomass in each location at the end of every month
Average fish weight (kg)	Average fish weight in a farm
Feeduse (tonnes)	Monthly feed uses for a farm.
Fish mortalities	Amount of fish that for some reason die each month.
Fish escapes	Total amount of fish that escaped per month.
Misc. losses	Amount of fish lost to misc. causes per month.
Amount of harvested fish	Amount of harvested fish per month.
Harvested biomass (kg)	The harvested biomass in kg per month.
Fish removals	The total amount of fish removed from one location per month.
Average harvest weight (kg)	The average weight of harvested fish.
Adult female lice	Amount of adult female lice per fish.
Mobile lice	Total amount of mobile lice per fish
Total amount of lice	Total amount of lice per fish
Temperature (°C)	Sea temperature
Number of cleaner fish released	The number of cleaner fish that has been released.
Number of bath treatments	Total amount of batch treatments per month.
Number of mechanical treatments	Total number of mechanical treatments per month.
PD	Dummy variable for the viral disease PD
ISA	Dummy variable for the viral disease ISA
North	Dummy variable for region
South	Dummy variable for region
Central	Dummy variable for region
Salmon (dummy)	Dummy variable for salmonid species.
Rainbow trout (dummy)	Dummy variable for salmonid species.

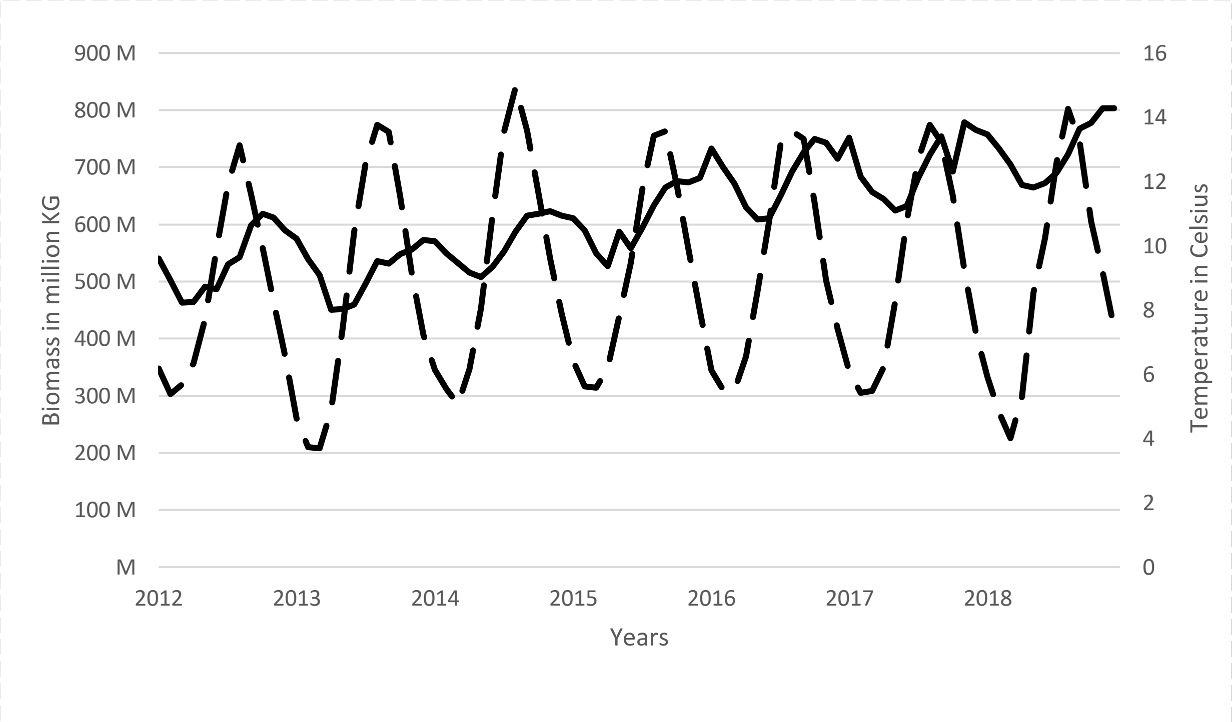


Figure 4.1 Average monthly biomass (Full) Average water temperature (Dash)

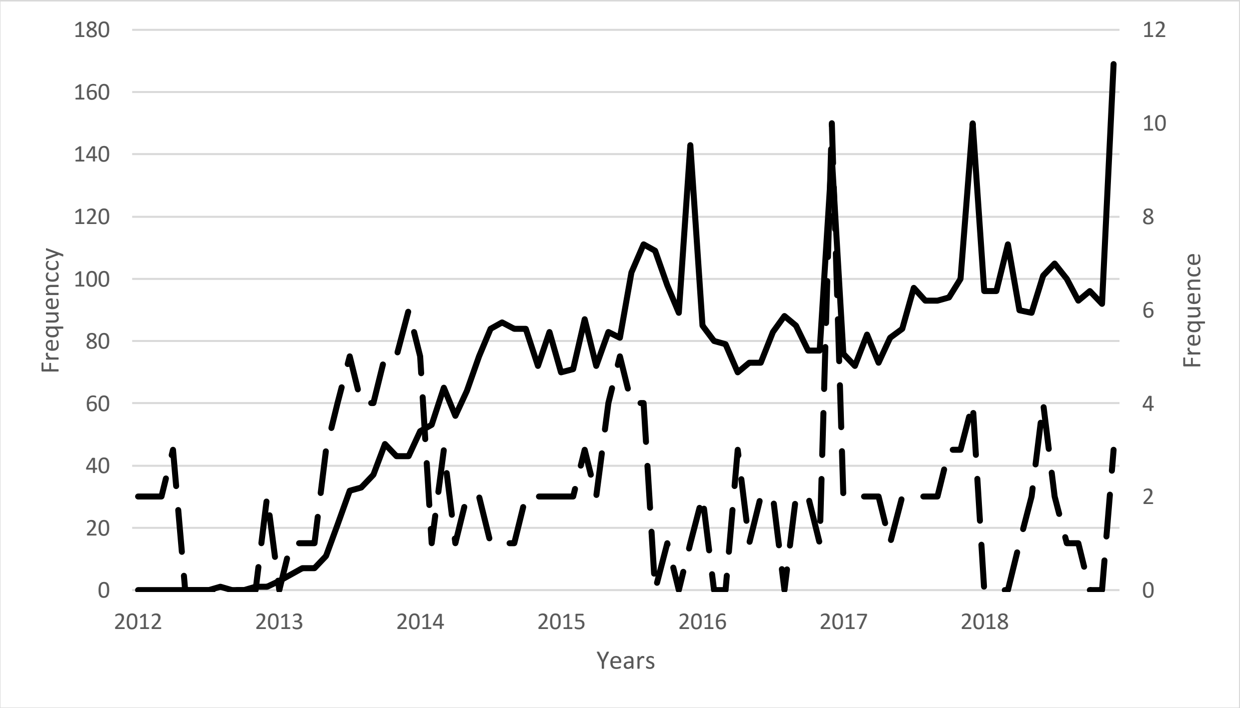


Figure 4.2. Average monthly infestations levels of PD(Full) and ISA (Dash)

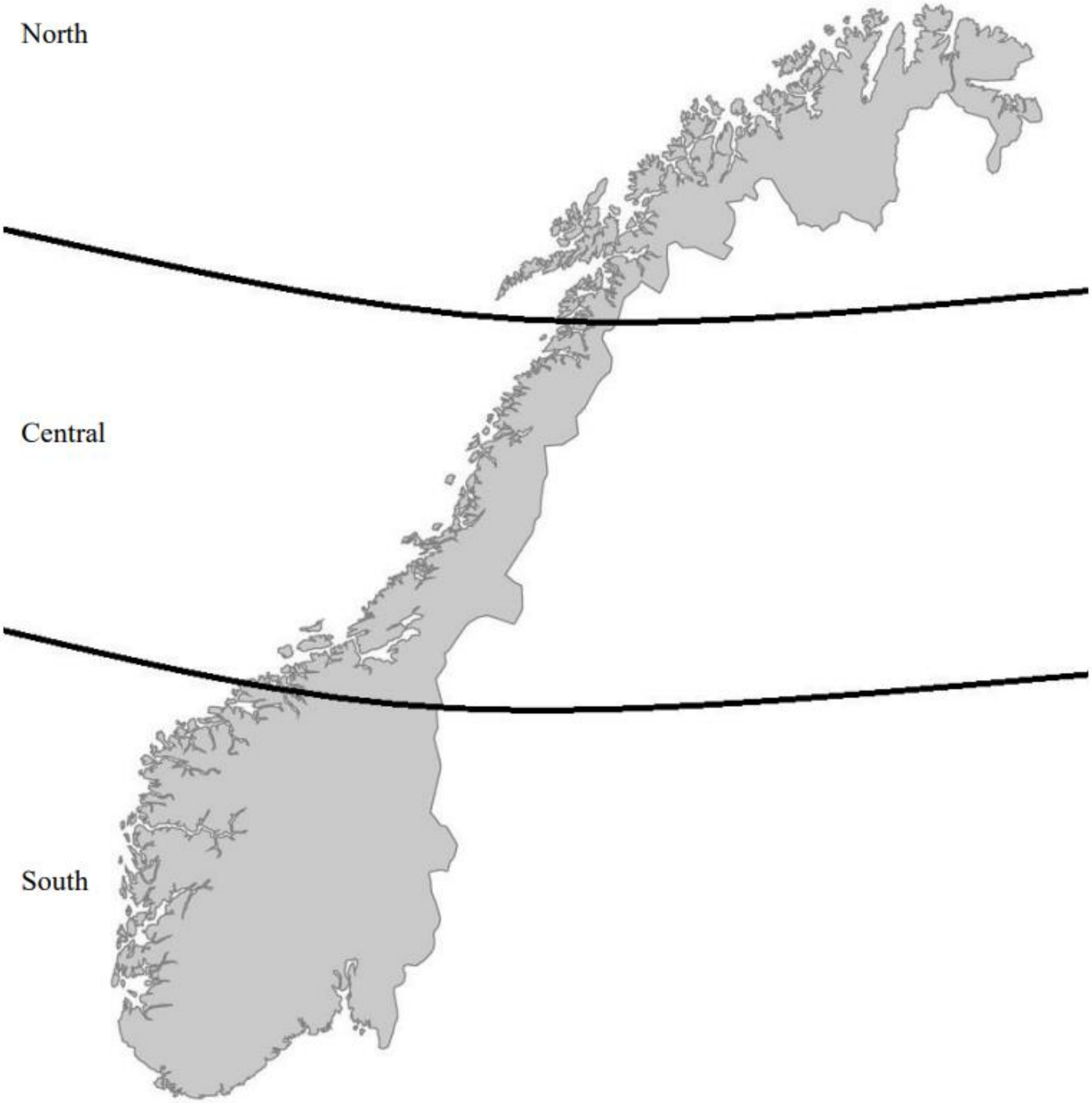


Figure 4.3. Geographical sones. Source: (Kaldheim et al. (2019).

4.1 Data Preparation

Due to a difference in reporting between the 3 datasets some data preparation needed to be done before the econometric model could be estimated. Both the dataset on lice and disease outbreaks were reported weekly while the biomass dataset was reported using monthly readings. To convert the weekly data into monthly data, several steps were undertaken, and, in some cases, completely new variables were created. Due to the nature of data collection I could only convert up to the least detailed data series regarding time, meaning that the data needed to be either summer or averaged depending on time dependencies. The weekly datasets were merged on each farm specific number, year, and month. Any farms only present in one of the datasets were omitted as this could mean no measurements were taken. Many of these omitted variables come from onshore facilities, but some onshore facilities were still omitted for lacking data.

Based on the work of Kaldheim et.al (2019) many of the improbable datapoints were omitted as erroneous reporting. The likelihood of these reporting's being true are deemed so low that they are emitted in fair of them interfering with the results. It seems that my tolerance for omission is even lower than Kaldheim et al. (2019) as my final dataset contains less points even though I have 1 more year of data. This can also be due to the fact that a third dataset containing viral disease are incorporated.

Unlike Kaldheim et al. (2019) the proxy variable MAS was calculated before the merging of the datasets to ensure that none of the otherwise complete production cycles would be omitted based on the omission criteria.

Tabell 4.1.3. Steps undertaken to merge datasets.

Step	Data set	Description
Grouping from weekly to monthly data. Grouped by farm, year, and month.	Viral disease and treatment	Viral disease was calculated as number of months the site had been infestated. To capture the difference in consequence depending on infestation duration.
Grouping from weekly to monthly data. Grouped by farm, year, and month	Lice and lice treatment	Lice and temperature were averaged over a month on a specific location nr. Treatments options were summed for each location, resulting in a number that corresponds to the number of treatments per month.
Grouping of datapoints from the same farm, year, and month	Biomass data	Some reporting's of several datapoints for the same farm and month were founded, these were summed for time-dependent variables and left as is for time-independent variables. All farms that were missing data were omitted.
Merging of the 3 datasets.	Final data set	The viral disease data set and the lice and lice treatment set were combined with the biomass dataset. When merging the disease and biomass datasets, all missing datapoints were set as 0 months of infestation. This is because the dataset on disease outbreaks only contained positive or suspected positive cases. As for the lice and lice treatment datasets, all non-compliant data points were deleted as all farms are required by law to report their results, and all non-reports are omitted.

Variable generation and removals.

Nor the dataset from The Norwegian directory of fishery or Barentswatch contained any parameter for how long the fish has been in the sea or any indication on how long production cycles lasted or which fish was part of which production cycle. As both Kaldheim et al. (2019) and Abolofia et al. (2017) did, the author has also created a proxy variable for fish age called MAS (Months at sea). But unlike the previous work done on this topic I have determined that some of the datapoints was lacking in such a degree that the MAS variable did not make sense and was therefore not computed. In some rare cases, over long periods smolt was gradually released into the pens over a period, this combined with gradual removals made it such that the average fish weight stayed constant over long periods. This in combined with production cycles where no start or finish was identified, referring to production cycles that had both release and harvest removed in the earlier stages of data merging resulting in roughly 7,000 datapoints being left blank. The methodology for creating the MAS variable is similar to the one used by Kaldheim et al. (2019). First the start of each production cycle was identified by looking for datapoints that had smolt released for the first time after a biomass of 0 was observed, if the average fish size however was low, but no datapoints for smolt released was identified, the production cycle was identified by harvest instead. It was then counted backwards from harvest to by the mean production cycle length which was 18 months. When both the start and end of the production cycles were identified the rest of the months were filled in given that certain criteria were upheld. For instance, the difference in dates between the 2 datapoints could not exceed 1 month and the average fish size would need to be relatively constant or increasing. The first datapoints of each cycle was imputed as blank and the same goes for the ones with no identifiable start. MAS had a mean of 9.27 and a 95% percentile of 19, giving the same results as Kaldheim et al. (2019). But with slightly less MAS observations overall, I suspect that the MAS also has an impact on the regression, which is why the author chose to emit the ones that had no real meaning.

Further refining of data set consisted of removing all total lice counts over 20 as this is deemed highly improbable , the same goes for water temperature under 2 degrees, average fish size over 10 kgs, all biomass growth over 200 % and biomass losses of over 80%. (Introduced in section 5.1).

5.Methodology

This chapter will contain the strategy and methodology used to estimate the biological and economic impacts of the notifiable salmon diseases ISA and PD. First a model for the private cost of fish disease is presented, this will account for both indirect and direct cost. Then the dependent variable is presented, and lastly the panel data estimators are compared, and their differences accounted for.

5.1 Empirical models

To be able to answer the research question at hand, a model for the private cost of PD and ISA must be created. The empirical model for fish biomass growth is based on the one from Abolofia et al. (2019) with modifications done by Kaldheim et al. (2019). The conceptual model for private cost of fish disease is a variant of the one devised by Abolofia et al. (2017).

Private cost of ISA PD

A model for the private cost of fish disease can be constructed by using some of the components from Abolofia et al. (2017) equation of discounted profits for the farmer which was based on sea lice treatments. By replacing the factors that account for sea lice levels with fish disease and omitting the parts that account for bath and mechanical treatments of lice, we end up with a equation for the farmers discounted profits:

$$\Pi(\mathrm{T}) = \mathrm{P}(\mathrm{T}) \times (B_0 + \int_0^T \dot{B}\big(t, D(t)\big) \times dt) \times e^{-rT} - C_f \int_0^T FCR \ \times \dot{B}\big(t, D(t)\big) \times e^{-rT} \times dt$$

Eq.5.1

Where T is harvest time, P(T) is the sell price of fish per kg, B_0 is the initial fish biomass which is free of fish disease, $\dot{B}(\cdot)$ is fish biomass growth, and D(t) is the fish disease state. C_f is the price of feed per unit, FCR is the feed conversion ratio and r is the farmers discount rate.

Equation 5.1 can be used to measure the economic impact of fish disease on a farmers discounted profits over a single production cycle. If we then compare a fixed time interval where the fish is free of disease with one that is infected with either PD or ISA, we can then generate the cost of fish disease for a certain time period, in this case a production cycle. :

$$\Pi(\mathrm{T})^{No\ disease} - \Pi(\mathrm{T})^{Disease} = e^{-rT} \times \mathrm{P}(\mathrm{T}) \sum_{i=1}^{I} \int_{ti-1}^{ti} (\dot{B}(t,0) - \dot{B}(t, D(t)))dt - C_f \sum_{i=1}^{I} \int_{ti-1}^{ti} \Big(\dot{B}(t,0) - \dot{B}\big(t, D(t)\big)\Big) \times e^{-rT} dt$$

Eq.5.2

This first part of this equation simply compares the biomass each month for 2 scenarios, one where the fish is free of fish disease and one where the fish is infected with either PD or ISA. The disease is hypothesized to reduce biomass growth and therefor has a direct cost for the farmer in reduced revenue. The second part of the equation looks at how the fish is hypothesized to have a reduced apatite when infected, which will result in a net saving for the farmer. To estimate the difference in biomass between these scenarios it is necessary to estimate a empirical model of fish biomass growth that is dependent on the disease state of the fish.

Biological Growth Model

With the information from The Norwegian directory of fisheries and Barentswatch it is possible to quantify the biological growth rate of salmonids in fish farms. It is then possible to quantify the impact of PD and ISA on the biological growth rate through a regression analysis. To generate this variable, it is important to quantify the added biomass for each month, this is referred to ass ancillary biomass (AB_{it}) (Abolofia et al. 2017). AB_{it} accounts for all the biomass that is added or removed from the pens each month, the change in biomass that is not due to natural growth.

$$AB_{It} = Stocking_{it} - Harvesting_{it} - Mortalities\ _{it} - Removals_{it} - Escapes_{it} \\ - Misc.Losses\ _{it}$$

Each term in the equation is expressed in terms of biomass (kg). And every variable except harvesting is presented in terms of number of fish. The product of number of fish and average fish size is therefor used for the remainder of AB_{it}. Since average fish size is reported at the end of each month, an average of time average fish weight$_t$ and average fish weight $_{t-1}$ is used. Our dataset contains no values for weight of fish that is stocked, and average of the current month is used instead. With that in mind, the definition of biological growth rate of farm biomass is expressed as:

$$r_{it=}\frac{(Biomass_{it}-AB_{it})-Biomass_{it-1}}{Biomass_{it-1}} \qquad \text{Eq.5.3}$$

Where *Biomass* is the standing biomass, *I* is the Ith farm and t is the time in months in a production cycle on a specific farm, *I*.

To measure the impact of fish disease on biological growth rate it is necessary to transform the Eq.5.3 to a nonlinear function of explanatory variables that are time dependent, the regression variables that will be estimated in later sections. $\ln(1+r_{it}) = x'_{it}\beta$, where x'_{it} is a vector consisting of all the explanatory variables that affect growth rate, and β is the estimated weights for the explanatory variables. When allowing for time-specific effects δ_t to capture seasonality effects, and farm specific effects c_i and an idiosyncratic error term u_{it}, we get the dependent variable in our regression (Abolofia et al. (2017):

$$\ln\left(\frac{Biomass_{it} - AB_{it}}{Biomass_{t-1}}\right) = x'_{it}\beta + \delta_t + c_i + u_{it} \qquad \text{Eq.5.4}$$

To ensure the use of the correct panel estimators for this regression, a series of tests and regressions will be completed. An overview of possible panel estimators and regression tests will be discussed further in this chapter. The choice of dependent variable, and the reasoning behind the way it is presented is also to make it easy to use the estimated results to generate a biomass loss in terms of kgs, this will be further discussed in the result section of the thesis. The empirical model is identical to the ones used by Kaldheim et al. (2019). And is as mentioned devised from the same research paper by Abolofia et. al. (2017).

5.2 Panel data

The merged dataset now consists of 43,588 observations from 1,041 farms stretching form the entire length of Norway over an 84-month period. This kind of data is called panel data or longitudinal data and has both elements of time series data and cross-sectional data, meaning they have observations over time for different entities. This panel data set enables the possibility to perform an empirical study of the impact of fish disease on biomass growth, which will in turn be used compute the private cost of disease. The approach to panel data estimators will be simulare to the one described by Abolofia et al. (2017). This approach starts by looking at the mechanism behind the multiple linear regression.

The model for any multiple linear regression starts with the equation for the dependent variable:

$$y_{it} = \alpha + x'_{it}\beta + z'_{it}\gamma + c_i + u_{it} \qquad \text{Eq.5.6}$$

Where y_{it} is the dependent variable which is the starting point of your regression, α symbolizing a constant or the y intercept, x' is a vector of time-varying variables with corresponding estimated impact β, z' being a vector of time-invariant variables with corresponding estimated impact γ, c_i to account for entity specific effects and u_{it} is the idiosyncratic error term.

For multiple linear regression to hold all the 4 conditions mentioned below need to be upheld:

1. *Linearity*

A linear relationship between the independent, dependent variables, entity specific effects and idiosyncratic error term. If for some reason the independent and dependent variables are nonlinear, one will often find the independent variables impact on the dependent variable to be underestimated (Jason w. Osborne et al. 2002).

2. *Normally distributed residuals*

Multiple linear regression assumes that the residuals are normally distributed with an expected value of 0.

3. *No multicollinearity*

Variables are not highly correlated, highly correlated independent variables can skew the econometric results if not accounted for, often tested for using the Variance Inflation Factor (VIF).

4. *Independent error terms*

Residuals should be uncorrelated.

5. *Homoscedasticity*

Variance of the residuals should be equal for every level of the explanatory variables.

There are 2 main techniques to analyze panel data, Fixed effects model and random effects model:

Fixed effects model

Fixed effects models are used when you are only interested in analyzing the impact of variables that vary over time. FE explores the relationship between predictor and outcome variables within an entity (Country, County, Person, Religion). Each entity has its own individual characteristics that can influence the predictor variables. For instance, if being a member of a Fishing club for salmon can influence your opinion on fish farms, or if the fact that you are a man has an influence on how you view politics etc. etc. The idea behind FE is then to control for this potential within bias. FE removes the effect of time-invariant characteristics so we can assess the net effect of the independent variables on the dependent variable.

With a FE model it is also assumed that the time-invariant characteristics are unique to the individual or entity and should not be correlated with other individuals or entities, each entity is unique and there entity's error term and constant should not be correlated. If the error terms are correlated, FE is not a suitable method to use. This is the main rational behind the Hausman test which is used in this thesis to decide between FE model and a Random-Effects model (Torres-Reyna, 2007).

The equation for FE can be represented as:

$$y_{it} = \alpha + x'_{it}\beta + u_{it} \qquad \text{Eq.5.7}$$

Where y_{it} is the dependent variable, α the intercept, x'_{it} the explanatory independent variables, β the coefficient for the independent variables, and u_{it} the error term.

Random effects model

The rationale behind random effects models are that, unlike the fixed effects model, the variation across entities are assumed to be random and not correlated with the dependent or independent variables in the model. If you have reason to believe that differences across entities, farms in our case have an impact on your dependent variable, then you should use a random effects model. In our case, if you believe that there are some characteristics that are inherent in a farm location that impact the growth rate, random effects models are best suited.

An advantage of this is that you can include time invariant variables, i.e. variables that do not vary over time, like gender, place of birth etc.etc. Random effects assume that the entities error term is not correlated with the independent variable which allows for time-invariant variables to play a role as independent variables. The general equation for random effects is presented as:

$$y_{it} = \alpha + x'_{it}\beta + u_{it} + c_i \qquad \text{Eq. 5.8}$$

Where y_{it} is the dependent variable, α the intercept, x'_{it} the explanatory independent variables, β the coefficient for the independent variables, u_{it} the error term and c_i representing the entity specific effects. In contrast to FE models, were c_i is removed, RE models account for this within variation.

6. Analyses and Results

In this chapter the regression results for the biological growth model will be presented and an overview of econometric testing will be given. Since econometric estimations on this dataset had been done before I was expecting to get the same results regarding regression method. I started construction of the model with a notion that I was going to end up with fixed effects model just like Kaldheim et al. (2019) and Abolofia et al. (2017). After econometric testing, the hypotheses that a fixed effects model was the best estimator was confirmed. After the regression results and the testing has been accounted for, marginal effects of temperature, fish size and number of lice for the interactional terms are presented. Then the estimated variables can be used to produce an overview of lost biomass in locations with PD and ISA will be presented along with an overview of associated private cost for the farmer, based on the model in 5.1

6.1 Econometric Results

To produce the best estimators for the model a series of tests have been done to ensure the right use of estimator models. First a simple OLS model was constructed, which based on econometric test results was built upon until the final regression modal was constructed. The final fixed effects model will be presented, along with a stepwise overview of econometric testing, the model was gradually made to fit better and better based on AIC criterion, which will be elaborated more in the upcoming section. With that in mind the final regression model became:

$$lngrowth_{it} = \propto + Months\ at\ sea\ _{it}\beta_1 + ILA\ _{it}\beta_2 + PD\ _{it}\beta_3 + Feeduse\ _{it}\beta_4 + Feeduse^2\ _{it}\beta_5 + Average\ fish\ weight\ _{it-1}\beta_6 + Average\ fish\ weight^2\ _{it-1}\beta_7 + Number\ of\ fish\ _{it-1}\beta_8 + Temperature\ _{it-1}\beta_9 + Temperature^2\ _{it-1}\beta_{10} + Total\ amount\ of\ lice\ _{it-1}\beta_{11} + PD \times temperature\ _{it-1}\beta_{12} + PD \times Number\ of\ mechanical\ treatments\ _{it}\beta_{13} + PD \times Average\ fish\ weight\ _{it-2}\beta_{14} + \delta_t + c_i + u_{it} \quad \text{Eq.6.1}$$

This is the final estimation of the explanatory variables impact on the dependent variable $lngrowth_{it}$ represented in Eq. 5.4. Table 6.1 provides an overview of all variables.

Tabell 6.1.1 Variable overview in the final fixed effects model

Variable	**Description**
$lngrowth_{it}$	Dependent variable, based on monthly growth rate
$Months\ at\ sea_{\ it}$	Proxy variable for month of production cycle, expected that growth rate may vary over month of the production cycle.
$ILA_{\ it}$	Dummy variable for the disease ILA, expected to reduce growth rate
$PD_{\ it}$	Dummy variable for the disease PD, expected to reduce growth rate
$Feeduse_{\ it}$	Feed use in tonnes, higher feed use is predicted to increase growth rate
$Feeduse^{2}{}_{\ it}$	Feeduse squared, to capture expected diminishing returns in feeduse
$Average\ fish\ weight_{\ it-1}$	The average fish weight with a 1-month lag, as the average weight of fish the previous month is expected to influence growth rate.
$Average\ fish\ weight^{2}{}_{\ it-1}$	The above-mentioned effect is predicted to have a diminishing return
$Number\ of\ fish_{\ it-1}$	Fish density is expected to have an impact on growth rate, enters with a 1-month lag
$Temperature_{\ it-1}$	Higher temperature is expected to increase biological growth rate, enters with a 1-month lag
$Temperature^{2}{}_{\ it-1}$	The above-mentioned effect is predicted to have diminishing returns
$Total\ amount\ of\ lice_{\ it-1}$	Total amount of lice at end of last month, enters with a 1-month lag, is expected to decrease growth rate
$PD \times temperature_{\ it-1}$	Interactional term with PD and temperature, to capture how temperature effects locations infected with PD
$PD \times Number\ of\ mechanical\ treatments_{\ it}$	Interactional term with PD and number of mechanical treatments, to capture how this effects location infected with PD
$PD \times Average\ fish\ weight_{\ it-2}$	Interactional term with PD and average fish weight, it is expected that smaller fish suffer larger biomass loss due to PD.

Breusch-Pagan Lagrange Multiplier Test

After construction of a simple OLS model a Breusch-Pagan Lagrange Multiplier Test is used to determine whether an OLS estimate or random effects estimate can be used. It determines whether the model can be estimated using multiple linear regression or if it needs a panel estimator. It was strongly hypothesized that an OLS estimator would fall short.

A Breusch-Pagan Lagrange multiplier test, tests against the null hypothesis that the variance across entities is zero. Meaning that there is no significant difference across units i.e. no panel effect. In our case that would mean that all locations could be counted as 1 if the null is not rejected. This is part of the reason why this hypothesis is hard to believe, as the panel consist of farms from all over Norway (Torres-Reyna, 2007).

Under the null hypothesis that variance across entities is zero, a STATA test yielded a result “Chibar2” of 263.68, which suggest strong variance across entities and the null hypothesis is rejected. Meaning that a fixed effects estimator is much better suited than an OLS estimation. This also fits well with the logical assumption that this can not hold true.

Durbin-Wu-Hausman Test

Since the test for OLS vs Random effects concluded that a panel estimator must be used, the next question is now which one? Fixed effects versus Random effects. To decide between these to estimators a Durbin-Wu-Hausman test or just Hausman test for short can be run. Where the null hypothesis that the preferred estimator is random effects vs the alternative which is fixed effects. The null hypothesis is whether the unique errors (u_i) are correlated with the regressors. As discussed in chapter 5, this is the difference between the two panel estimators (Torres-Reyna, 2007)

Under the null hypothesis the STATA command for a Durbin-Wu-Hausman test was run, yielding a result of chi2(29) = 81.03 strongly rejecting the hypothesis that the errors are correlated to the regressors. Leaving us with a fixed effects model.

Testing for serial correlation

Sever serial correlation, can if left uncontrolled severely decrease the amplitude of the standard deviation on estimated variables. This can skew the results and it is therefore important to test for serial correlation between the errors terms in the panel estimation. This can be done through a Wooldridge test for autocorrelation through STATA. It tests against the null hypothesis that no serial correlation is present in the variables error terms. Through STAT command xtserial F (1,910) of 65.237 is given, strongly rejecting the null hypothesis that there is no serial correlation. This is accounted for through variance-covariance estimator (VCE) adjustment for clustering at the panel-level through STATA.

Testing for group-wise heteroskedasticity

Even though the errors within each entity can be homoscedastic, its variance can be different between entities. This phenomenon is called group-wise heteroskedasticity and can be tested through STATA commands. The null is homoskedasticity or constant variance across entities. Through the command Xttest3, the modified Wald test for groupwise heteroskedasticity in fixed effect regression model yields a Chi2(933) of 17280.09 strongly rejecting the null hypothesis that the fixed effects model show group wise homoskedasticity. (Torres Reyna (2007).

6.2 Regression results

Table 6.2 contains all the regression results from FE model 1-3, these models increase in complexity and we can see that the R^2 increases from 0.428 to 0.4912 in FE model 3. The AIC criterion decreases from -44,000 to -48,500, indicating that this both captures the most amount of variation in the dependent variable and is of overall higher “quality”, according to AIC. The R^2 of 0,4912 is higher than Kaldheim et al. (2019) and Abolofia et al. (2017) and shows that the estimation captures a great deal of the variation in growth rate. If you take the nature of the data and consider all the variables that could affect growth rate in a natural setting, an R^2 of 0,4912 is rather good. All results are significant above a 1 % significance level, except ISA. The independent variable ISA, which is a dummy variable for the disease ISA, had a t-stat of -0.95 and is only significant above a 35% significance level. Why ISA and every other variable with ISA as an interactional term is statistically insignificant will be discussed in chapter 7. From this point forward, biomass loss and cost associated with ISA will be scrapped, as there are no variables to work from.

Table 6.2.1 Regression results.

Variable	**FE Model 1**	**FE model 2**	**FE model 3**
Months at sea $_{it}$	-.0092(.00086)	-.0091(.00095)	-.00275(.000775)
ISA $_{it}$	-.0200(.0119)	-.0153(.0129)	-.0112(.0118)
PD $_{it}$	-.0236(.0025)	-.0255(.00344)	-.0176(.00352)
Feeduse $_{it}$(Tonnes)	.000134(.0000245)	.000180(.000026)	.000310(.0000395)
Feeduse^2 $_{it}$(Tonnes)	-7.66e-08(2.33e-08)	-9.15e-08(2.56e-08)	-1.49e-07(3.80e-08)
Average fish weight $_{it-1}$(kg)	-.0234(.00309)	-.0294(.00344)	-.0932(.00627)
Average fish weight^2 $_{it-1}$(kg)	-	-	.00661(.000836)
Number of fish $_{it-1}$	-8.13e-09(7.06e-09)	-3.61e-08(8.31e-09)	-6.62e-08(7.96e-09)
Temperature $_{it-1}$(°C)	.0264(.00182)	.0249(.00173)	.02113(.00172)
Temperature^2 $_{it-1}$(°C)	-.001126(.0000791)	-.001(.000078)	-.000841(.0000771)
Total amount of lice $_{it-1}$	-.00836(.000698)	-.00747(.000690)	-.00521(.000674)
PD × temperature $_{it-1}$	-	-.00433(.000372)	-.00389(.000395)
PD × Nr. Mechanica treatments $_{it-1}$	-	-.01157(.002182)	-.006957(.001996)
PD × Average fish weight $_{it-2}$	-	.02051(.001765)	.0166(.002224)
Year fixed effects	YES	YES	YES
Farm fixed effects	YES	YES	YES
Month fixed effects	YES	YES	YES
Observations	32,450	29,813	29,813
Number of farms	936	933	933
Observations per farm	34.7	32	32
R^2(within/overall)	0.4339/0.4279	0.4658/ 0.4572	0.4993/ 0.4912
AIC	-44,646.2	-46,909.17	-48,835.33

6.3 Biomass Loss for a Typical Production Cycle

To estimate the reduction in revenue caused by a typical PD infestation, the lost biomass that can be directly linked to PD have to be established. Since PD is regressed as a dummy variable, we can create datasets for every region, meaning North, Central and South. Where all parameters are set at average values for that region and use the regression results i.e. the estimated coefficients together with the average values of each independent variable to create 2 different scenarios. One where its free of PD, meaning 0 months of the production cycle is affected by PD, and one where all months are under PD infection. Then a full overview of estimated biomass losses is generated for each month of the production cycle, this can then be inserted into Eq. 5.2 to get an overview of the cost associated with PD for one production cycle. The coefficients for the independent variables are taken from Table 6.2 FE model 3. When the estimation for the dependent variable lngrowthrate, introduced in Eq. 5.4, is complete, it must be transformed from a % change in biomass, to a change in biomass in kg. This is done through the following Equation:

$$\widehat{g_t} = (e^{\widehat{y_t}} - 1) \times Biomass_{t-1} \quad \text{Eq.6.2}$$

Where $\widehat{g_t}$, is the difference in biomass between t and t-1, $\widehat{y_t}$ is the estimation of the dependent variable and $Biomass_{t-1}$ is the average biomass for a specific region at MAS_{t-1}. The difference in biomass growth between PD free scenario and one with PD infestation is then calculated:

$$\Delta\widehat{g_t} = \hat{g}_t^{NO\ PD} - \hat{g}_t^{PD} \qquad \text{Eq.6.3}$$

Figure 6.1 contains average values for all the variables that are represented in the equation for the dependent variable Eq. 6.1. These graphs show a difference in many of the average values. For the south and central regions, the average water temperatures are higher, this results in higher growth rates. Higher lice counts are also found in the in regions with higher average water temperatures. Colder waters will affect the growth rate negatively when a location is infected with PD. The harvesting of fish seems to be done in stages as the biomass starts declining from MAS~16 when the average fish size still increases but biomass declines. Table 6.2 shows the estimated biomass loss for each MAS in terms of tons, the model seems to have some problems estimating biomass loss at high values of MAS.

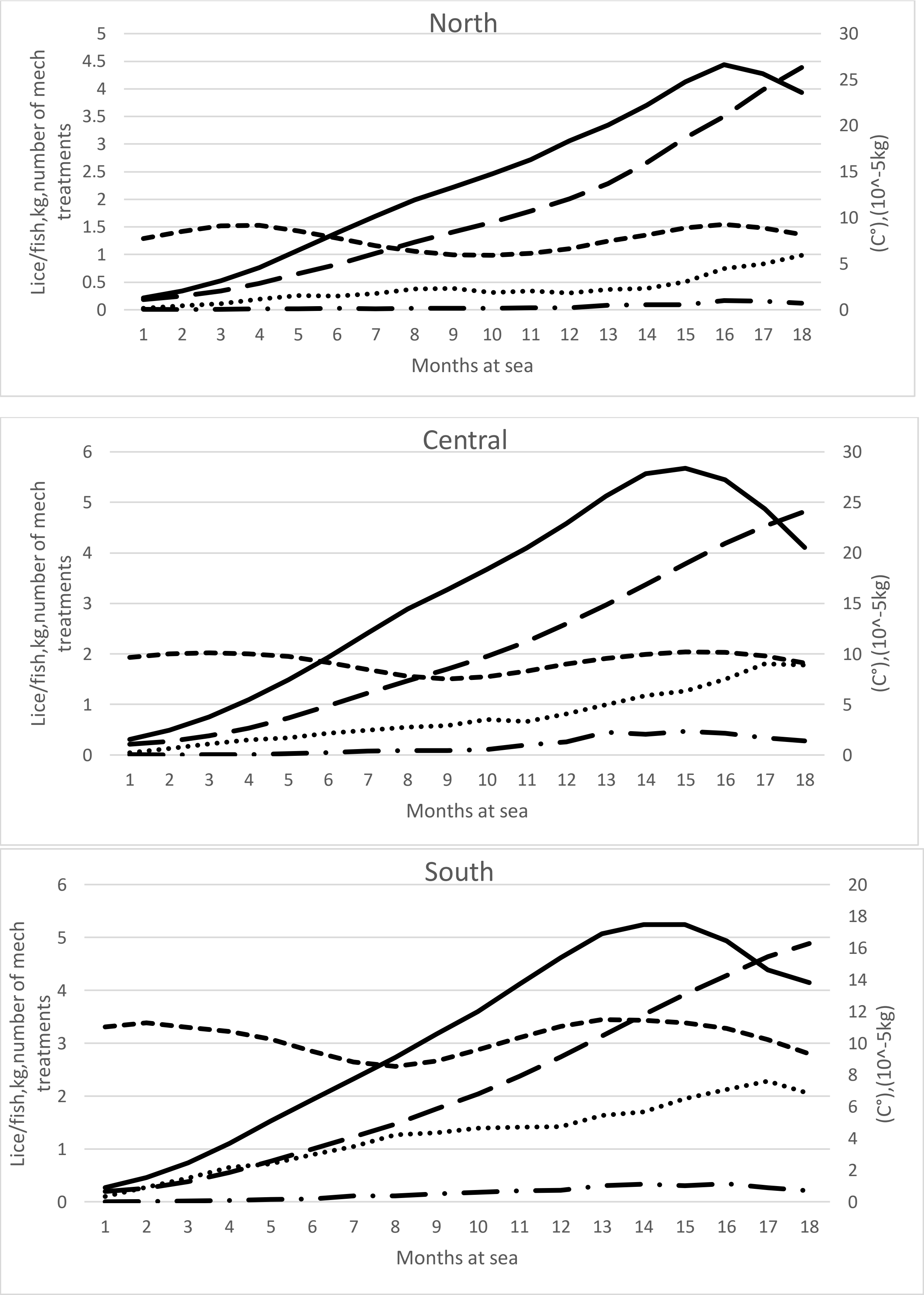


Figure 6.3.1 Average values for each region, Biomass (Solid), Average fish weight (Long dash), Temperature (Short dash), Lice per fish (Dot), Number of mechanical treatments (Dash-dot)

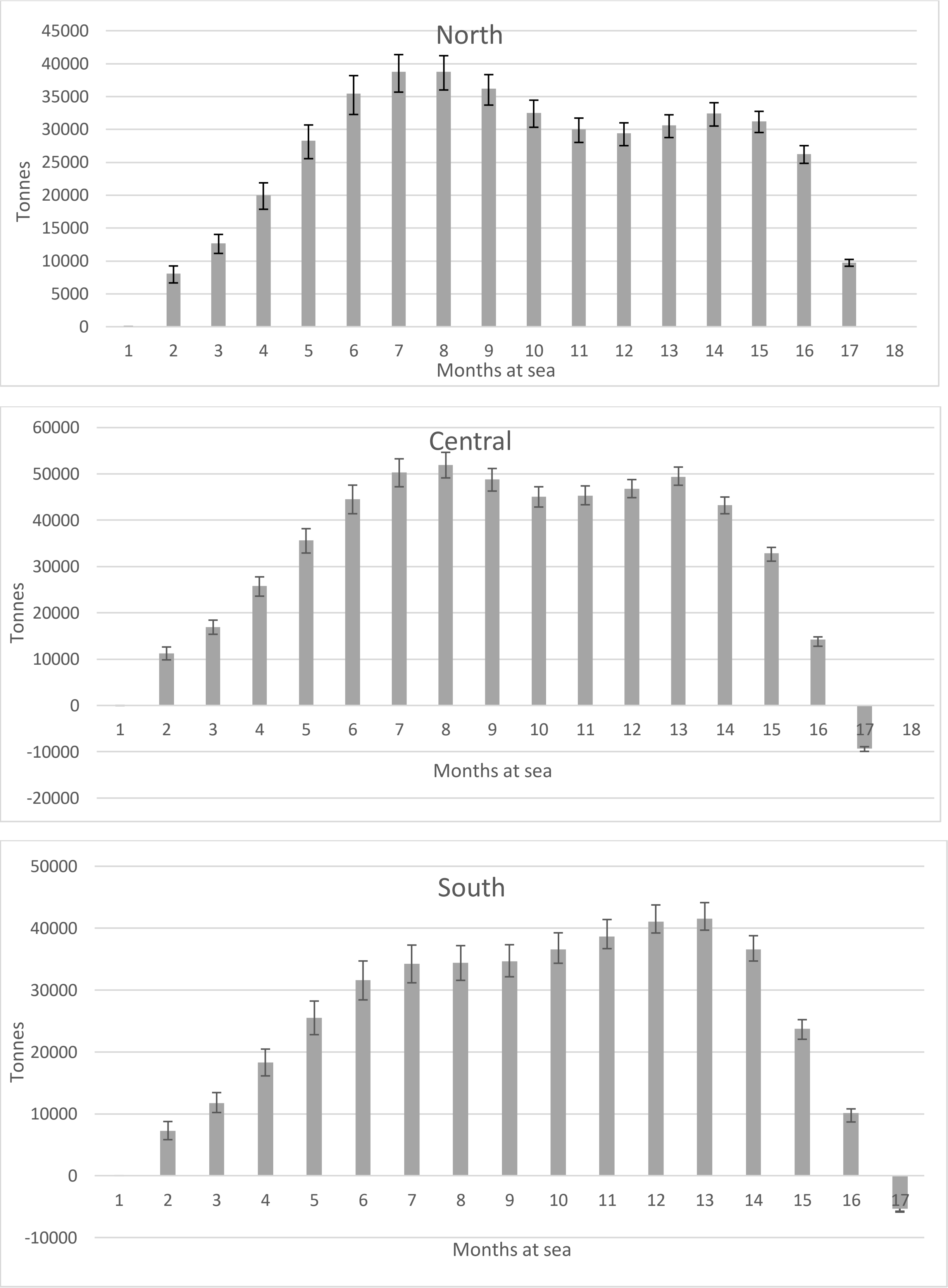


Figure 6.3.2 Lost biomass per month in an average production cycle. 95% Cis

6.4 Indirect cost of PD

To calculate the indirect costs associated with the viral disease PD, a parameterized version of Eq.5.2 will be used. By applying this equation for an average production cycle in each region with PD infestation, we can get an estimation for how much an average infection will cost in terms of indirect cost associated with biomass losses and reduced appetite. Eq. 6.4 shows the parameterized adoption of Eq.5.2.

$$Lost\ revenue = \frac{P}{(1+r)^T} \sum_{t-1}^{T} \Delta\widehat{g_t} - \sum_{t-1}^{T} \frac{c_{f\times FCR}}{(1+r)^T}\ \Delta\widehat{g_t} \qquad \text{Eq.6.4}$$

Table 6.3.1 Parameter values

Parameter	Value	Description
P	47.62 NOK/kg	Average spot price for salmon form 2012/2018, Average of weekly prices. (Fishpool 2020).
r	0	Farmers discount rate.
c_f	11.80 NOK/kg	Feed price (Iversen et al. 2017)
FCR	1.15	Feed conversion ratio (Marine harvest 2018)

Unlike Kaldheim et al (2019), it is not possible to calculate the average cost for a specific region as the infection is binary, compared to the average lice levels used in their thesis. The reported costs are there for presented as the cost of an average PD infestation for 1 production cycle for each region. The average length of an PD infestation is 14 months. This is the basis for the numbers calculated in table 6.4. The fact that the average length of a PD infestation is longer than 1 year also makes it difficult to estimate any average costs per year as the infestation spreads through multiple years.

Tabell 6.3.2. Cost elements of total indirect cost for an average PD infestation level.

Region	Revenue loss (MNOK)	Feed cost savings (MNOK)
Infestation from MAS 1-14		
North	17.77[18.97,16.38]	5.06[5.41,4.67]
Central	24.52[25.88,23.13]	6,99[7.38,6.59]
South	18.67[20.22,17.28]	5.32[5.76,4.92]
Infestation from MAS 2-16		
North	20.13[21.4,18.65]	5.74[6.1,5.32]
Central	26.23[27.61,24.76]	7.48[7.87,7.06]
South	19.94[21.52,18.46]	5.68[6.13,5.26]

Tabell 6.3.3 Cost of average PD infestation by region

Region	Total cost of PD (MNOK)	Cost/kg of harvested fish (NOK)	% of revenue
North	13.55[14.43,12.52]	5.38[5.74,4.98]	11.31[12.04,10.45]
Central	18.15[19.13,17.12]	7.22[7.6,6.83]	15.42[16.24,14.55]
South	13.80[14.92,12.78]	8.85[9.57,8.20]	18.59[20.1,17,21]

Note: The total costs are an average of infestation between MAS 1-14 and 2-16. Cost/kg of harvested fish is calculated based on the average biomass close to harvest, % of revenue is calculated using the same average harvested biomass.

By table 6.4 it is evident that the total cost of PD is not the best metric to compare costs across regions, this is caused by a large difference in standing biomass across regions. The longer south the more prevalent the fish farms are but they are on average smaller in size. The higher average water temperatures and increased lice counts increases losses a % of revenue from 11.31 % in the north to 18.59 % in the south. With the central regions somewhere in between. There is also a higher number of mechanical treatments in the south, which is estimated to have a negative impact on growth rate in combination with PD. The reasoning behind the estimation varying from between MAS 1-14 and 2-16 is that the fish is more prone to catching PD in the early stages of saltwater production making this a lot more likely scenario than infections happening in MAS~4-6. It should also be noted that the model struggles with estimating losses at high values of MAS.

As mentioned earlier the average length of a PD infestation is 14 months, the data used for calculating average yearly costs are new PD outbreaks by year. This in combination with the average cost of 1 outbreak will at least give some estimation of associated yearly costs. The total cost of a PD for year t^1, is based on outbreak data from t^{t+1} as the time of slaughter is the point where the loss is realized. The data points for outbreaks per year is not categorized by region, so for this estimation to make sense an average of the total costs for each region is used. The results are shown in Figure 6.3

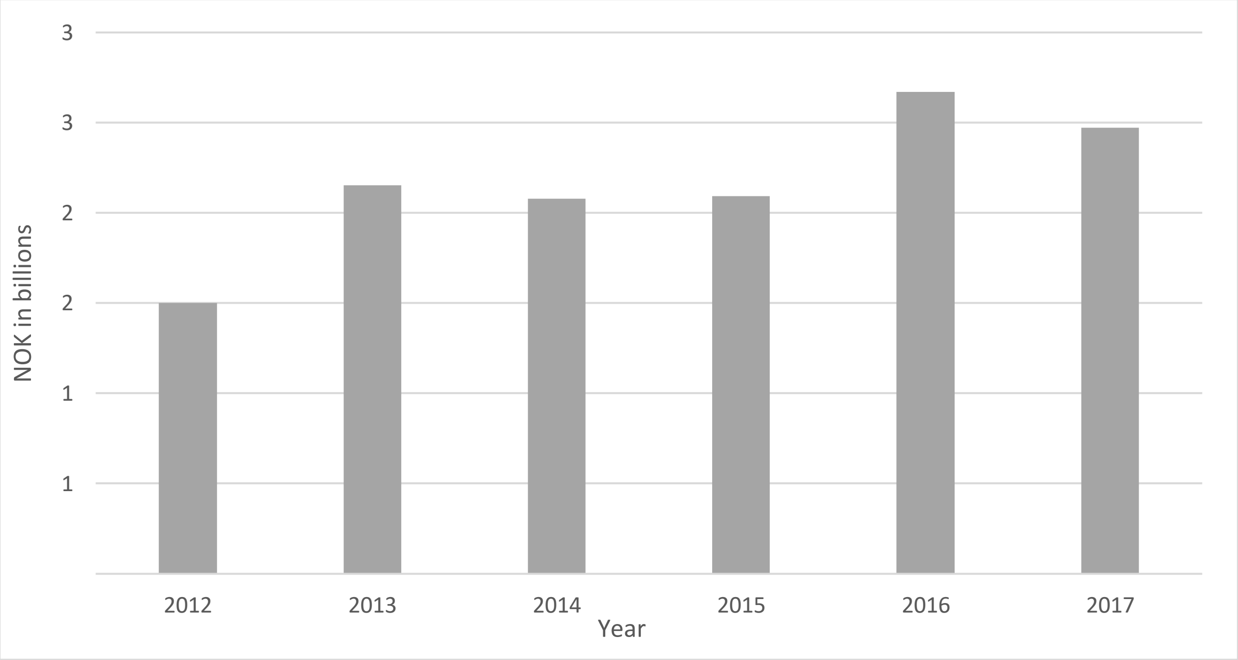


Figure 6.3.3 Estimated yearly losses for PD

7.Discussion

This chapter will contain discussions regarding potential errors in data, regression, and results. Discussion around the estimate of ISA and some discussion over the direct cost associated with viral disease based on earlier research will also be reported.

7.1 Potential sources of error

DATA

Through the refining process on the datasets several “out of place” observations where done, which can be a result of erroneous reporting. Many of these observations were removed but the presence of many erroneous reporting leaves a notion that some datapoints still left in the complete dataset may be invalid. In addition to erroneous reporting in the dataset some production cycles that were never harvested, most likely the fish where transferred to a new location, had smolt releases for the entire production cycle. It is not unlikely that these cases have a negative impact on the accuracy of the final model, as it is hard to estimate coefficients for such behavior. There were also reporting several datapoints for the same variable for the same month, meaning that there is a possibility that one/both is erroneous. A sensational amount of datapoints for viral disease was lost in the merging with biomass data. The dataset for biomass had all onshore facilities emitted, as these are free of lice and are harder to estimate using parameters like temperature, it is plausible that the dataset for viral disease had these included, but no information on this was present in the dataset. This resulted in a final dataset consisting of less than ideal amounts of disease points, which might have negatively impacted the panel estimation. Regarding the estimation of the proxy variable “Months at sea” it is worth mentioning that the total amount of observations is slightly lower than that of Kaldheim et al. 2019. As this variable is supposed to transfer some information about the production cycles, I have emitted all MAS variables that cannot with certainty be estimated. This includes production cycles without clear starts and harvest months, as this is basically just guesswork.

Regression

It would be appropriate to capture the effect time has on viral disease, to account for the expected differences in growth rate for months of infection. No method for capturing this effect was identified and a dummy variable was used. It is hypothesized that the viral diseases have different effects on the fish based on infection length. It was obvious from the results on lost biomass that the model struggled with estimating biomass for higher values of MAS. The inclusion of the interactional term between *Average fish weight* and *PD* showed how the fish is more prevalent to the negative consequences of PD when the average weight is low. No diminishing returns where possible for this making it possible that the model overcompensated for fish weight. The inclusion of a general interactional term for fish weight captured some of this effect, as shown by the difference in estimated values for FE model 2 and FE model 3. A further investigation on this issue could have yielded better results. The inclusion of the average weight^2 variable also corrected for some of the estimated coefficients for both average weight and MAS, as they are most likely highly correlated.

Results

Given the binary nature of fish disease meaning there are no degrees of infection or marginal effects on infection, it is not possible to compute an average infection per farm. With this fact in mind the results are more useful in the perspective of one production cycle. Instead of viewing the results as an average cost per region/year as Kaldheim et al.2019 did, it is much more accurately viewed as a binary situation. This also means that the results can be further worked upon by estimating how individual disease outbreaks by region. The results in Figure 6.3 reflect this and I would advise the reader to analyze the results on a per production cycle basis. It would also be wise to reflect over the fact that biomass$_{it-1}$ is used in the calculations for lost biomass, which results in an estimation off lost biomass that has its origin in a recorded biomass where the reduction in biomass from time t-2 is not accounted for. As this is present in both the PD free and PD infected biomass growth, the error is negligible.

Removal of ISA estimations

As a result of the omission of many datapoints on disease in the merging of datasets, resulting in only 172 months of ISA infection being present in the regression, all variables estimated for the impact of ISA on the dependent variable were statistically insignificant. This resulted in no calculations for the impact of ISA on growth rate and no results were reported. The lack of datapoints is not something that can be worked around and no other datasets where found. It is possible that many cases of ISA are found in onshore facilities, but no definitive evidence for that is presented.

Previous work done on quantifying the cost of viral disease.

A master's thesis on quantifying the cost of viral disease in aquaculture by Henrik Vandvik Vedeler from 2017 used data collected from fish farms to quantify the yearly total costs of viral disease in Norwegian aquaculture. A comparison between the results for biological losses show a significantly lower estimated total cost, this is most likely due to his manual data collection method leaving many cases of PD unaccounted for. Especially on a year to year basis as he has a low level of consistency in data over the period. He has no reports on a production cycle basis, but the fact that the estimated total cost for biological losses I have reported is higher, at least show some evidence that the numbers are representative. More intriguing is the results estimated for cost associated with treatment and prevention. If the reported direct cost for PD is accurate for the data he has collected, a % of direct to indirect costs can be used to give an estimation on cost for treatment, prevention etc.

The cost of biological losses account for 59% of the total cost of PD, this is computed as an average from 2013-2016 (Vedeler 2017). This number can be used to estimate the total cost of PD, but has a high degree of uncertainty, as the datasets and method are completely different. The estimations are presented in Figure 6.4.

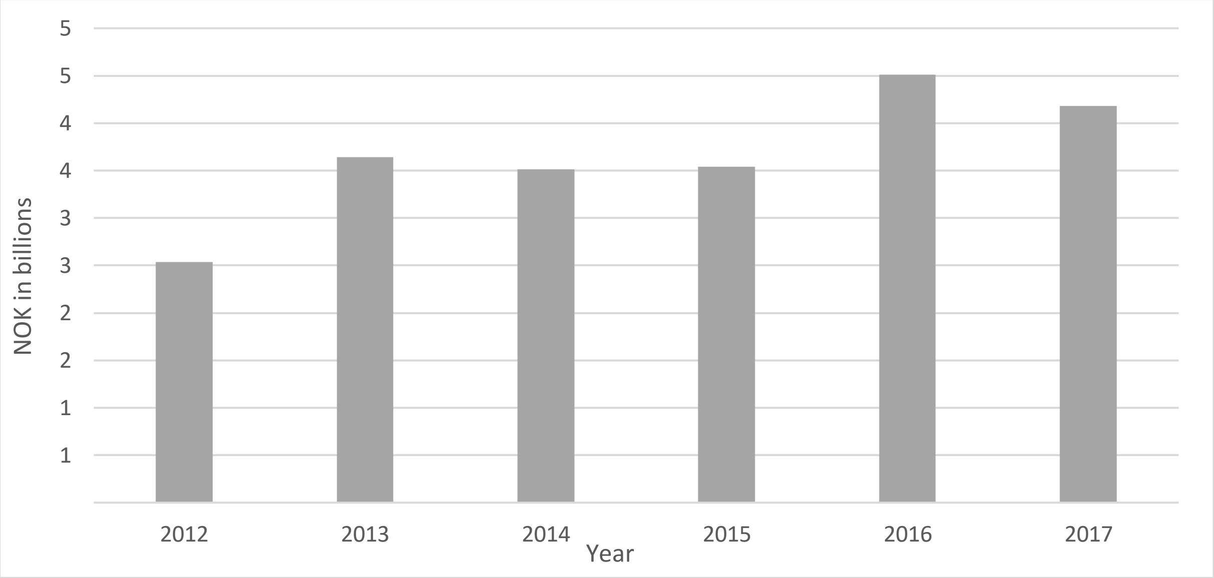


Figure 7.1.1 Total cost of PD by year.

8.Conclusion

It is observed that pens effected with PD have reduced growth rates and increased production cycles due to a negative impact on growth rate. The notion that PD reduces fish growth was reflected in the results from this thesis. PD infestations on average cost the farmers 15.16 MNOK if isolated to one location. This is a significant amount and accounts for approximately 15% of revenues for the farmer. The northern regions see a smaller loss in terms of % of revenue loss, most likely due to the lower temperature. The farms are on average larger meaning the net loss is larger in MNOK per pen, but they are proportionally smaller compared to central and southern regions. Both an increase in sea water temperature and number of mechanical treatments have shown to have a negative impact on growth rate in PD infested locations. While the interactional term between average fish weight and PD infestation has shown a proportionally larger impact on small fish.

The average biological losses per location according to Vedeler (2017) varies from 11.0 to 31.7 MNOK, averaging at 20 MNOK from 2012-2016. This is slightly higher on average than the 15.16 MNOK reported in this thesis. The variation in Vedelers findings might suggest that the smaller sample size have scattered the results. On the other hand, Vedelers reporting reflect the variation in salmon price, unlike here were it is reports as an average over the data duration.

This study amplifies the belief that mitigating effects around PD infestation is profitable for the farmers, and the impacts of PD infestations in terms of biomass loss is significant. The mitigating actions taken by farmers in recent year have shown results and with economic estimation, like the one reported here, might help the industry invest in better prevention and treatment options. The increased prevalence of mechanical treatments might also drive the biological losses further. Further adding to the point made by Kaldheim et al. (2019). That the direct consequence of treatment options on biological growth rates outweigh the potential reduction is lice levels.

9. References

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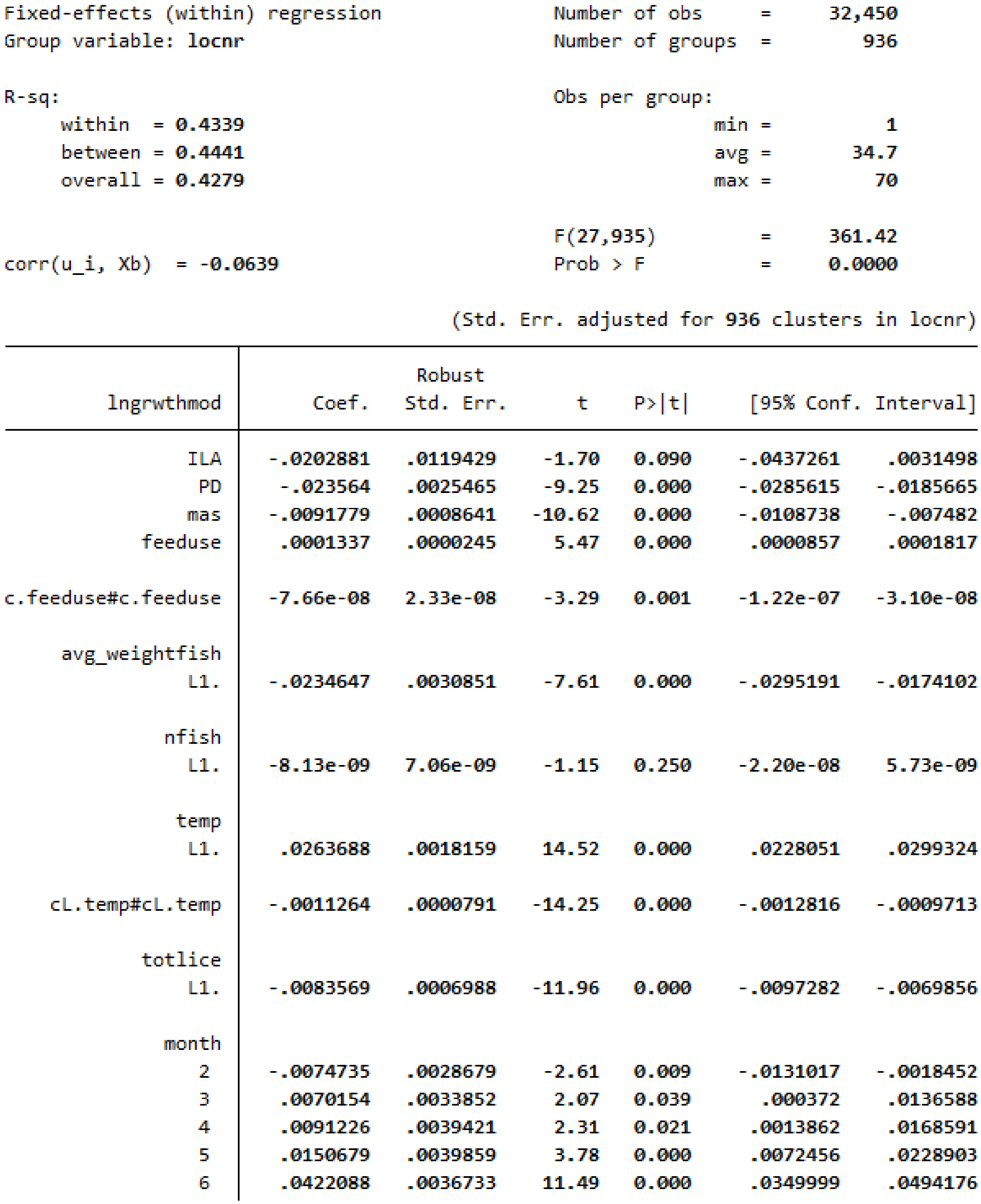
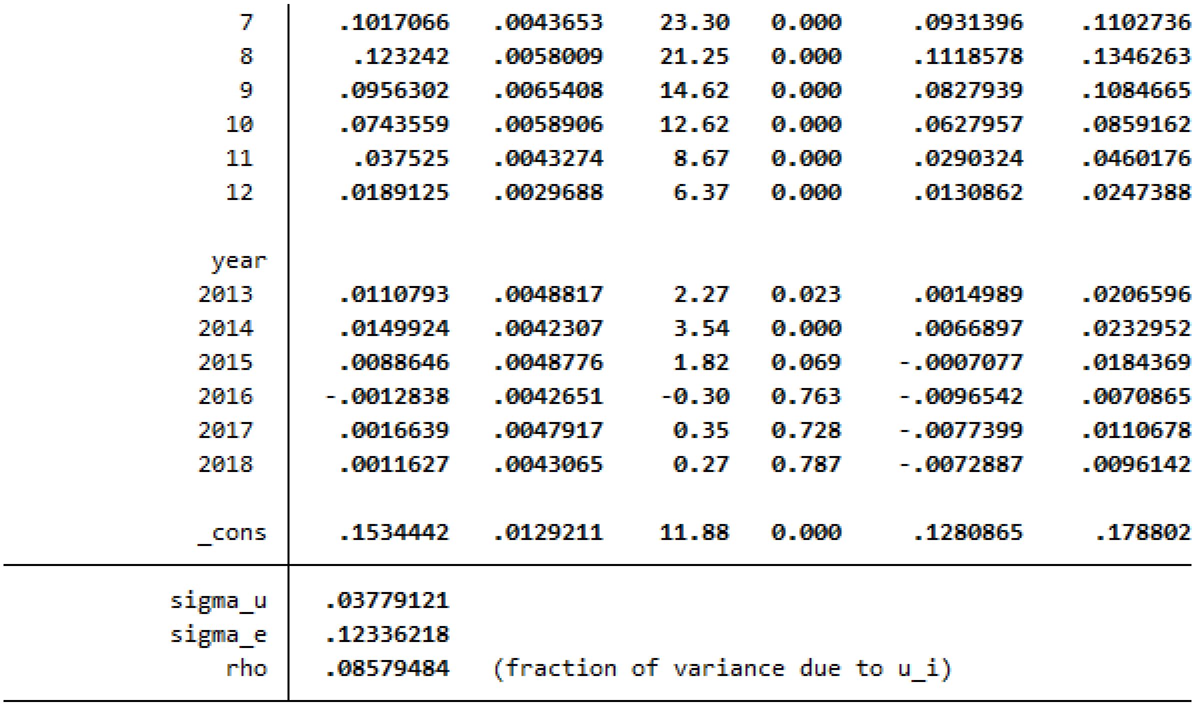
10. Appendix

Appendix 1: STATA OUTPUT FOR ALL FE MODELS



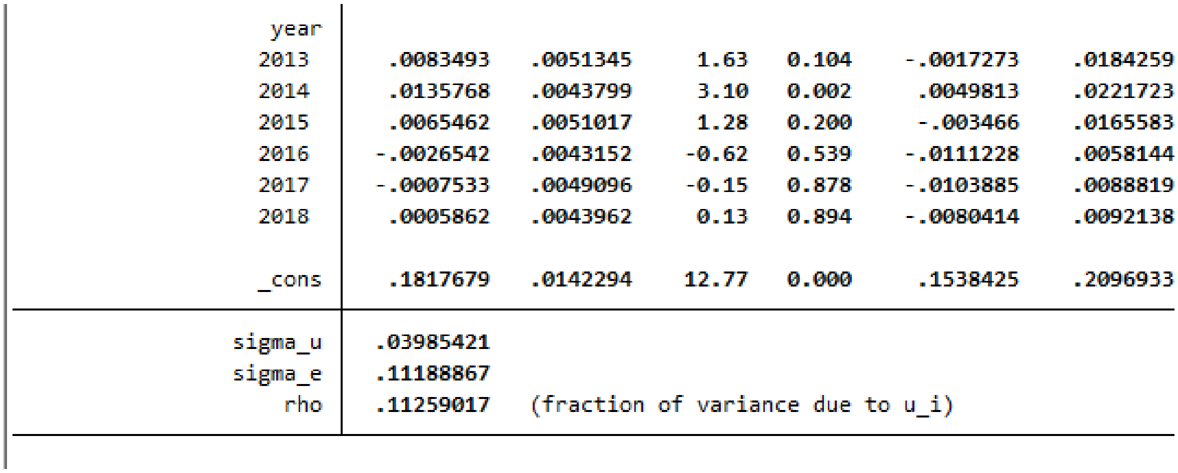
```
Fixed-effects (within) regression               Number of obs     =     32,450
Group variable: locnr                           Number of groups  =        936

R-sq:                                           Obs per group:
     within  = 0.4339                                         min =          1
     between = 0.4441                                         avg =       34.7
     overall = 0.4279                                         max =         70

                                                F(27,935)         =     361.42
corr(u_i, Xb)  = -0.0639                        Prob > F          =     0.0000

                                 (Std. Err. adjusted for 936 clusters in locnr)
-------------------------------------------------------------------------------
                    |               Robust
         lngrwthmod |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------+----------------------------------------------------------
                ILA |  -.0202881   .0119429    -1.70   0.090    -.0437261    .0031498
                 PD |   -.023564   .0025465    -9.25   0.000    -.0285615   -.0185665
                mas |  -.0091779   .0008641   -10.62   0.000    -.0108738    -.007482
            feeduse |   .0001337   .0000245     5.47   0.000     .0000857    .0001817
                    |
c.feeduse#c.feeduse |  -7.66e-08   2.33e-08    -3.29   0.001    -1.22e-07   -3.10e-08
                    |
      avg_weightfish |
                L1. |  -.0234647   .0030851    -7.61   0.000    -.0295191   -.0174102
                    |
              nfish |
                L1. |  -8.13e-09   7.06e-09    -1.15   0.250    -2.20e-08    5.73e-09
                    |
               temp |
                L1. |   .0263688   .0018159    14.52   0.000     .0228051    .0299324
                    |
    cL.temp#cL.temp |  -.0011264   .0000791   -14.25   0.000    -.0012816   -.0009713
                    |
            totlice |
                L1. |  -.0083569   .0006988   -11.96   0.000    -.0097282   -.0069856
                    |
              month |
                  2 |  -.0074735   .0028679    -2.61   0.009    -.0131017   -.0018452
                  3 |   .0070154   .0033852     2.07   0.039      .000372    .0136588
                  4 |   .0091226   .0039421     2.31   0.021     .0013862    .0168591
                  5 |   .0150679   .0039859     3.78   0.000     .0072456    .0228903
                  6 |   .0422088   .0036733    11.49   0.000     .0349999    .0494176
```



```
           7 |   .1017066   .0043653    23.30   0.000     .0931396    .1102736
           8 |    .123242   .0058009    21.25   0.000     .1118578    .1346263
           9 |   .0956302   .0065408    14.62   0.000     .0827939    .1084665
          10 |   .0743559   .0058906    12.62   0.000     .0627957    .0859162
          11 |    .037525   .0043274     8.67   0.000     .0290324    .0460176
          12 |   .0189125   .0029688     6.37   0.000     .0130862    .0247388
             |
        year |
        2013 |   .0110793   .0048817     2.27   0.023     .0014989    .0206596
        2014 |   .0149924   .0042307     3.54   0.000     .0066897    .0232952
        2015 |   .0088646   .0048776     1.82   0.069    -.0007077    .0184369
        2016 |  -.0012838   .0042651    -0.30   0.763    -.0096542    .0070865
        2017 |   .0016639   .0047917     0.35   0.728    -.0077399    .0110678
        2018 |   .0011627   .0043065     0.27   0.787    -.0072887    .0096142
             |
       _cons |   .1534442   .0129211    11.88   0.000     .1280865     .178802
-------------+----------------------------------------------------------------
     sigma_u |  .03779121
     sigma_e |  .12336218
         rho |  .08579484   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

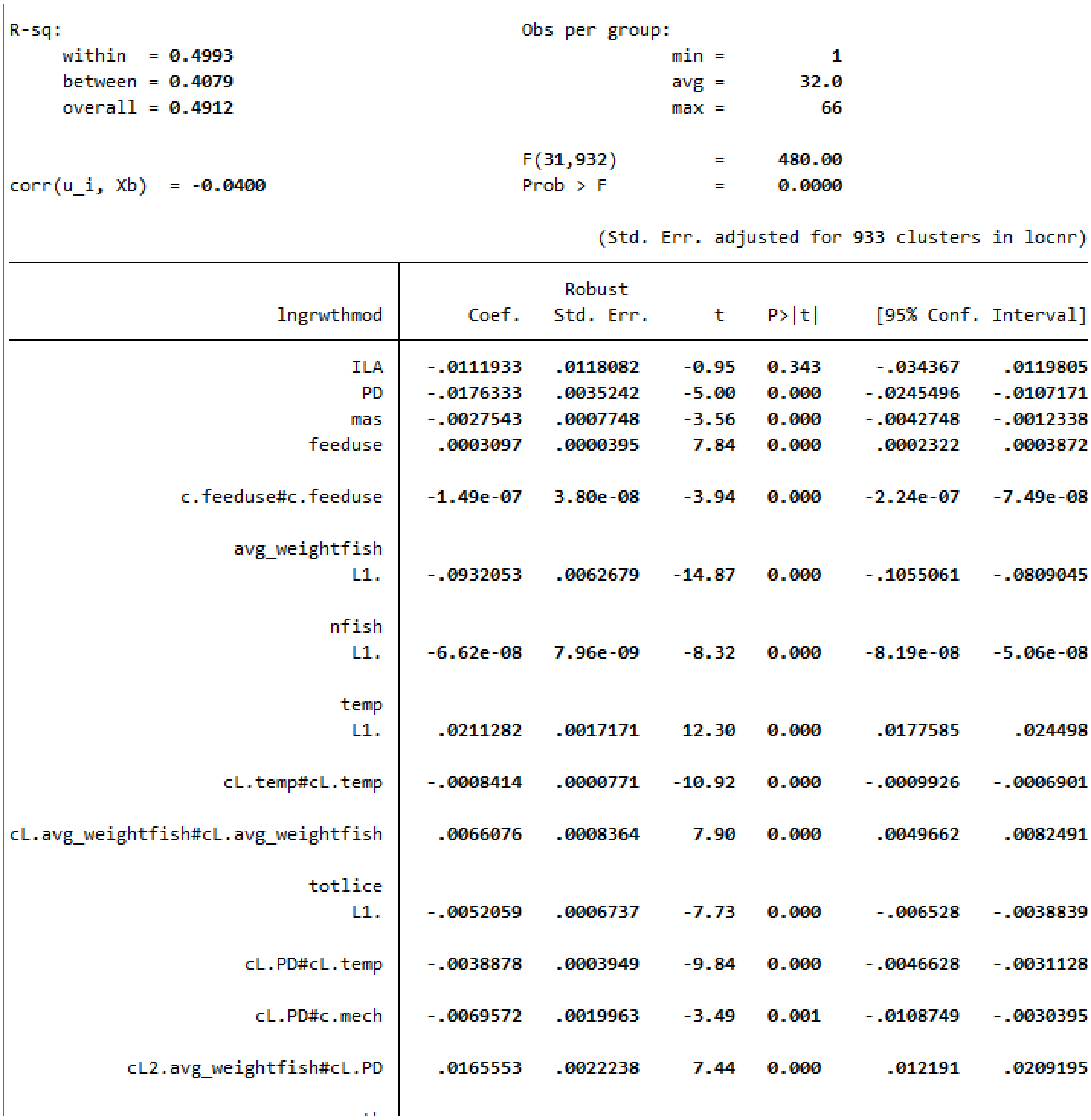
Figure 10.1 FE Model 1.

```
Fixed-effects (within) regression               Number of obs     =     29,813
Group variable: locnr                           Number of groups  =        933

R-sq:                                           Obs per group:
     within  = 0.4658                                         min =          1
     between = 0.3766                                         avg =       32.0
     overall = 0.4572                                         max =         66

                                                F(30,932)         =     329.69
corr(u_i, Xb)  = -0.0756                        Prob > F          =     0.0000

                                    (Std. Err. adjusted for 933 clusters in locnr)
------------------------------------------------------------------------------------
                         |               Robust
             lngrwthmod |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------------------+----------------------------------------------------------
                     ILA |  -.0153234   .0129615    -1.18   0.237    -.0407605    .0101137
                      PD |  -.0254965   .0034493    -7.39   0.000    -.0322659   -.0187272
                     mas |  -.0090875   .0009512    -9.55   0.000    -.0109542   -.0072208
                 feeduse |   .0001806   .0000264     6.83   0.000     .0001287    .0002325
                         |
     c.feeduse#c.feeduse |  -9.15e-08   2.56e-08    -3.57   0.000    -1.42e-07   -4.12e-08
                         |
          avg_weightfish |
                     L1. |  -.0294166   .0034187    -8.60   0.000    -.0361259   -.0227074
                         |
                   nfish |
                     L1. |  -3.61e-08   8.31e-09    -4.35   0.000    -5.24e-08   -1.98e-08
                         |
                    temp |
                     L1. |   .0249183   .0017263    14.43   0.000     .0215305    .0283062
                         |
          cL.temp#cL.temp |  -.0010012   .0000787   -12.72   0.000    -.0011556   -.0008467
                         |
                 totlice |
                     L1. |  -.0074684   .0006896   -10.83   0.000    -.0088217   -.0061151
                         |
            cL.PD#cL.temp |  -.0043281   .0003715   -11.65   0.000    -.0050572    -.003599
                         |
            cL.PD#c.mech |  -.0115683    .002182    -5.30   0.000    -.0158504   -.0072862
                         |
cL2.avg_weightfish#cL.PD |   .0205115   .0017645    11.62   0.000     .0170487    .0239743

                   month |
                      2  |  -.0072953   .0028742    -2.54   0.011    -.0129359   -.0016547
                      3  |   .0063405   .0033734     1.88   0.060    -.0002798    .0129608
                      4  |   .0145284   .0037147     3.91   0.000     .0072382    .0218186
                      5  |   .0195613   .0039525     4.95   0.000     .0118046    .0273181
                      6  |   .0342167   .0037794     9.05   0.000     .0267995    .0416339
                      7  |   .0935396   .0041297    22.65   0.000     .0854349    .1016443
                      8  |   .1107757   .0054045    20.50   0.000     .1001694    .1213821
                      9  |   .0783488    .006103    12.84   0.000     .0663716    .0903261
                     10  |   .0584345   .0053169    10.99   0.000         .048     .068869
                     11  |   .0286925   .0040144     7.15   0.000     .0208142    .0365708
                     12  |   .0145009   .0029262     4.96   0.000     .0087582    .0202436
```

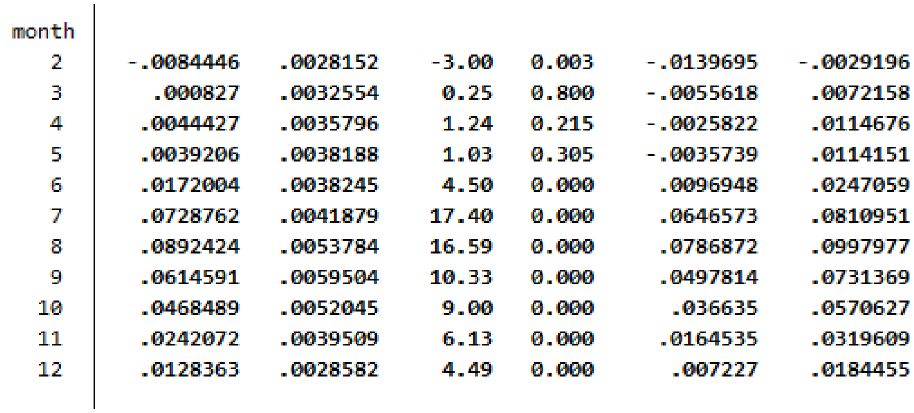


```
                 year |
                 2013  |   .0083493   .0051345     1.63   0.104    -.0017273    .0184259
                 2014  |   .0135768   .0043799     3.10   0.002     .0049813    .0221723
                 2015  |   .0065462   .0051017     1.28   0.200     -.003466    .0165583
                 2016  |  -.0026542   .0043152    -0.62   0.539    -.0111228    .0058144
                 2017  |  -.0007533   .0049096    -0.15   0.878    -.0103885    .0088819
                 2018  |   .0005862   .0043962     0.13   0.894    -.0080414    .0092138
                       |
                _cons  |   .1817679   .0142294    12.77   0.000     .1538425    .2096933
-----------------------+----------------------------------------------------------------
              sigma_u  |  .03985421
              sigma_e  |  .11188867
                  rho  |  .11259017   (fraction of variance due to u_i)
----------------------------------------------------------------------------------------
```

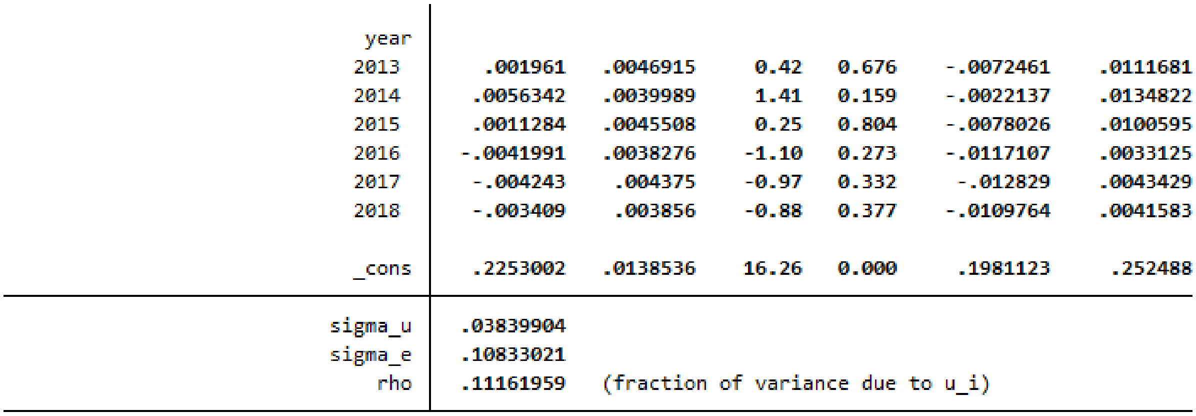
Figure 10.2 FE Model 2.



```
R-sq:                                           Obs per group:
     within  = 0.4993                                        min =          1
     between = 0.4079                                        avg =       32.0
     overall = 0.4912                                        max =         66

                                                F(31,932)          =     480.00
corr(u_i, Xb)  = -0.0400                        Prob > F           =     0.0000

                                      (Std. Err. adjusted for 933 clusters in locnr)
------------------------------------------------------------------------------------
                                  |               Robust
                      lngrwthmod  |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------------------------------------------------------------------------
                              ILA |  -.0111933   .0118082    -0.95   0.343     -.034367    .0119805
                               PD |  -.0176333   .0035242    -5.00   0.000    -.0245496   -.0107171
                              mas |  -.0027543   .0007748    -3.56   0.000    -.0042748   -.0012338
                          feeduse |   .0003097   .0000395     7.84   0.000     .0002322    .0003872
                                  |
              c.feeduse#c.feeduse |  -1.49e-07   3.80e-08    -3.94   0.000    -2.24e-07   -7.49e-08
                                  |
                    avg_weightfish |
                              L1. |  -.0932053   .0062679   -14.87   0.000    -.1055061   -.0809045
                                  |
                            nfish |
                              L1. |  -6.62e-08   7.96e-09    -8.32   0.000    -8.19e-08   -5.06e-08
                                  |
                             temp |
                              L1. |   .0211282   .0017171    12.30   0.000     .0177585     .024498
                                  |
                   cL.temp#cL.temp |  -.0008414   .0000771   -10.92   0.000    -.0009926   -.0006901
                                  |
cL.avg_weightfish#cL.avg_weightfish |   .0066076   .0008364     7.90   0.000     .0049662    .0082491
                                  |
                          totlice |
                              L1. |  -.0052059   .0006737    -7.73   0.000     -.006528   -.0038839
                                  |
                     cL.PD#cL.temp |  -.0038878   .0003949    -9.84   0.000    -.0046628   -.0031128
                                  |
                     cL.PD#c.mech |  -.0069572   .0019963    -3.49   0.001    -.0108749   -.0030395
                                  |
           cL2.avg_weightfish#cL.PD |   .0165553   .0022238     7.44   0.000      .012191    .0209195
                                  |
                               .. |
```



```
            month |
               2  |  -.0084446   .0028152    -3.00   0.003    -.0139695   -.0029196
               3  |    .000827   .0032554     0.25   0.800    -.0055618    .0072158
               4  |   .0044427   .0035796     1.24   0.215    -.0025822    .0114676
               5  |   .0039206   .0038188     1.03   0.305    -.0035739    .0114151
               6  |   .0172004   .0038245     4.50   0.000     .0096948    .0247059
               7  |   .0728762   .0041879    17.40   0.000     .0646573    .0810951
               8  |   .0892424   .0053784    16.59   0.000     .0786872    .0997977
               9  |   .0614591   .0059504    10.33   0.000     .0497814    .0731369
              10  |   .0468489   .0052045     9.00   0.000      .036635    .0570627
              11  |   .0242072   .0039509     6.13   0.000     .0164535    .0319609
              12  |   .0128363   .0028582     4.49   0.000      .007227    .0184455
                  |
```



```
             year |
             2013 |    .001961   .0046915     0.42   0.676    -.0072461    .0111681
             2014 |   .0056342   .0039989     1.41   0.159    -.0022137    .0134822
             2015 |   .0011284   .0045508     0.25   0.804    -.0078026    .0100595
             2016 |  -.0041991   .0038276    -1.10   0.273    -.0117107    .0033125
             2017 |   -.004243    .004375    -0.97   0.332     -.012829    .0043429
             2018 |   -.003409    .003856    -0.88   0.377    -.0109764    .0041583
                  |
            _cons |   .2253002   .0138536    16.26   0.000     .1981123     .252488
------------------+----------------------------------------------------------------
          sigma_u |  .03839904
          sigma_e |  .10833021
              rho |  .11161959   (fraction of variance due to u_i)
-----------------------------------------------------------------------------------
```

Figure 10.3 FE Model 3.