NTNU – Trondheim
Norwegian University of
Science and Technology

Smoother harvest of farmed salmon, value-adding or costly?

Investigating the consequences for the different players in the industry

Anja Graff Nesse
Frida Næss-Ulseth

Industrial Economics and Technology Management
Submission date: June 2014
Supervisor: Verena Hagspiel, IØT
Co-supervisor: Stein-Erik Fleten, IØT

Norwegian University of Science and Technology
Department of Industrial Economics and Technology Management

NTNU
Det skapende universitet

MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Nesse, Anja Graff**	Fødselsdato **30. mar 1990**
E-post **anjagraff@gmail.com**	Telefon **90056943**

2. Studieopplysninger

Fakultet **Fakultet for samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Investering, finans og økonomistyring**

3. Masteroppgave

Oppstartsdato **15. jan 2014**	Innleveringsfrist **11. jun 2014**
Oppgavens (foreløpige) tittel **Smoother harvest of farmed salmon, value-adding or costly?** **Investigating the consequences for the different players in the industry**	
Oppgavetekst/Problembeskrivelse The Norwegian salmon farming industry is a highly cyclical industry. Historically, salmon supply and salmon prices fluctuate from month to month throughout the year, creating uncertainty for the salmon farmers. With demand being stable, the unstable supply of salmon creates distortions in the salmon market. In this thesis we will investigate the advantages and disadvantages of a smoother harvest profile and what this would mean for the different players in the salmon industry. This we will do by comparing an optimal harvest profile with a smoother harvest profile through an optimization model, and talking to different interest groups such as producers, processors and regulators.	
Hovedveileder ved institutt **Førsteamanuensis Verena Hagspiel**	Medveileder(e) ved institutt **Stein-Erik Fleten**
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

Trondheim 04-04.14

Sted og dato

Student	**Hovedveileder**

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

NTNU
Det skapende universitet

MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Næss-Ulseth, Frida**	Fødselsdato **22. nov 1988**
E-post **frida.nu@gmail.com**	Telefon **92407884**

2. Studieopplysninger

Fakultet **Fakultet for samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Investering, finans og økonomistyring**

3. Masteroppgave

Oppstartsdato **15. jan 2014**	Innleveringsfrist **11. jun 2014**
Oppgavens (foreløpige) tittel **Smoother harvest of farmed salmon, value-adding or costly?** **Investigating the consequences for the different players in the industry**	
Oppgavetekst/Problembeskrivelse The Norwegian salmon farming industry is a highly cyclical industry. Historically, salmon supply and salmon prices fluctuate from month to month throughout the year, creating uncertainty for the salmon farmers. With demand being stable, the unstable supply of salmon creates distortions in the salmon market. In this thesis we will investigate the advantages and disadvantages of a smoother harvest profile and what this would mean for the different players in the salmon industry. This we will do by comparing an optimal harvest profile with a smoother harvest profile through an optimization model, and talking to different interest groups such as producers, processors and regulators.	
Hovedveileder ved institutt **Førsteamanuensis Verena Hagspiel**	Medveileder(e) ved institutt **Stein-Erik Fleten**
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

Sted og dato

Trondheim, 4.4.2014

Student

Frida Wess-Ulbell

Hovedveileder

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

NTNU
Det skapende universitet

SAMARBEIDSKONTRAKT

1. Studenter i samarbeidsgruppen

Etternavn, fornavn	Fødselsdato
Nesse, Anja Graff	**30. mar 1990**
Etternavn, fornavn	Fødselsdato
Næss-Ulseth, Frida	**22. nov 1988**

2. Hovedveileder

Etternavn, fornavn	Institutt
Hagspiel, Verena	**Institutt for industriell økonomi og teknologiledelse**

3. Masteroppgave

Oppgavens (foreløpige) tittel
Smoother harvest of farmed salmon, value-adding or costly?   **Investigating the consequences for the different players in the industry**

4. Bedømmelse

Kandidatene skal ha *individuell* bedømmelse ☐
Kandidatene skal ha *felles* bedømmelse ☒

Trondheim 4/04/14
Sted og dato

Anja Graff Nesse
Anja G Nesse

Hovedveileder

Frida Næss-Ulseth
Frida Næss-Ulseth

Originalen oppbevares på instituttet.

Problem Description

Main Title: Smoother Harvest of Farmed Salmon – Value-Adding or Costly?

Sub Title: Investigating the consequences for the different players in the industry

Problem Description:

The Norwegian salmon farming industry is a highly cyclical industry. Historically, salmon supply and salmon prices fluctuate from month to month throughout the year, creating uncertainty for the salmon farmers. With demand being stable, the unstable supply of salmon creates distortions in the salmon market.

In this thesis we will investigate the advantages and disadvantages of a smoother harvest profile and what this would mean for the different players in the salmon industry. This we will do by comparing an optimal harvest profile with a smoother harvest profile through an optimization model, and talking to different interest groups such as producers, processors and regulators.

Supervisors:

Verena Hagspiel

Stein-Erik Fleten

Sammendrag

Omtrent 60 % av all laks produsert i verden er oppdrettslaks. Tilbudet av Atlantisk laks i verden har mer enn doblet seg siden år 2000, med en årlig vekst på rundt 7 %. De største markedene for Atlantisk laks er per i dag EU og USA, men markeder andre steder i verden vokser raskt, noe som resulterer i en sterkt økende etterspørsel av laks. Oppdrettsnæringen i Norge har gjennom de siste tiårene opplevd en kraftig vekst og bransjen har konsolidert. Siden oppdrett av laks startet på 1970 tallet har den norske lakseindustrien beveget seg fra å være en lokal småskala industri til en global multinasjonal industri som eksporterer rundt 90-95 % av produksjonen til mer enn 100 land.

Historisk sett så har spot prisen på laks vært svært volatil. Hovedgrunnen til dette bunner i uelastisk tilbud av laks på kort sikt, noe som er en konsekvens av biologiske faktorer i produksjonen og en lang produksjonssyklus. Oppdrett av laks er en biologisk prosess, noe som medfører at realisert produksjon ikke alltid stemmer med planlagt produksjon. Dette kan føre til at lakseindustrien og markedet for laks kan oppleve perioder med overproduksjon og underproduksjon, noe som kan resultere i en fluktuerende laksepris. Ustabilt slakt og tilbud av laks og volatile laksepriser har resultert i uforutsigbare kontantstrømmer og varierende fortjenester for oppdrettere. Ustabilt tilbud av laks har også påvirket resten av verdikjeden, og ført til krevende situasjoner for mange aktører i bransjen.

I denne masteroppgaven har vi utviklet en matematisk modell for å finne det optimale tidspunkt for slakt av laks. Modellen legger til rette for ulike slaktestrategier ved å muliggjøre fordeling av slakt i spesifiserte måneder. Dette gjør det mulig å sammenligne en jevn slakting av laks med en ujevn slakt av laks. For at modellen skal være mulig å løse har vi gjort flere forenklinger. Vi har blant annet kun kalkulert for sesongbaserte variasjoner i pris. Produksjonskostnader og fiskevekst er antatt konstante parametere. I tillegg til en matematisk modell har vi gjennomført en analyse av verdikjeden for laks. Analysen er basert på intervjuer av ulike aktører i verdikjeden.

Målet for denne masteroppgaven er å undersøke om et jevnere uttak av laks kan skape større verdier i verdikjeden for laks. Ett mål har vært å beskrive verdikjeden for laks og undersøke hvilke utfordringer aktørene i verdikjeden møter som et resultat av ujevn slakt. Et annet mål har vært å utvikle en matematisk modell for det optimale tidspunkt for slakt av laks for å kunne sammenligne ulike slaktestrategier og avdekke verdien av et jevnt uttak av laks. Ett siste mål har vært å utføre en analyse av verdikjeden for å kunne avgjøre om et jevnere uttak av laks kan skape verdier for andre aktører i verdikjeden. Analysen er gjennomført gjennom intervjuer av ulike aktører. Konklusjonen vår er basert på resultater fra den matematiske modellen og verdikjedeanalysen.

Våre resultater viser at et jevnere uttak av laks vil koste oppdretter rundt 9 % av den potensielle fortjenesten generert fra produksjonen. Med andre ord så vil en jevnere slakt

av laks være mindre lønnsomt for oppdretter isolert sett. Videre så viser våre resultater at et jevnere uttak av laks vil medføre mindre biomasse i sjøen gjennom året sammenlignet med et ujevnt uttak, noe som er positivt for miljøet rundt oppdrettsmerdene. Resultater fra verdikjedeanalysen viser at det i all hovedsak er prosesserer som drar nytte av et jevnere uttak av laks. Et interessant funn fra våre analyser er at supermarkedkjeder ikke merker noe spesielt til svingninger i tilbud av laks. Dette indikerer at det norske markedet for laks blir mettet før laks eksporteres til utlandet.

Andre interessante funn er industriens bekymringer relatert til svært høye laksepriser. Våre analyser tilsier at svært høye laksepriser kan medføre økt internasjonal konkurranse og i tillegg forhøyede kostnadsnivåer, noe som kan true den norske oppdrettsnæringen på lang sikt. I tillegg så ønsker ikke regjeringen å dele ut flere konsesjoner i den nærmeste fremtid, noe som indikerer at det høye prisnivået på laks vil vedvare. Dette kan være skadelig for den norske oppdrettsnæringen. Gjennom våre analyser har vi fått bekreftet at regjeringen ønsker mer prosesseringsaktivitet i Norge. Vi finner dette interessant, i og med prosessering av laks i Norge vil være ulønnsomt så lenge høye laksepriser vedvarer, noe det mest sannsynlig vil gjøre ved at ingen ny kapasitet blir utdelt. I tillegg vil mer prosessering i Norge kunne medføre at flere tusen arbeidsplasser i Europa vil bli flyttet til Norge, noe som kan resultere i strengere tollbarrierer innført av EU. Dette kan ha fatale konsekvenser for norsk oppdrettsnæring som baserer seg i stor grad på internasjonal handel.

Abstract

About 60% of the world's salmon production is farmed. Supply of Atlantic salmon has more than doubled since 2000 with an annual growth of 7%. The EU and the US are by far the largest markets for Atlantic salmon. However, emerging markets are growing at significantly higher rates than these traditional markets, resulting in increasing demand for salmon. In Norway, the history of salmon farming is a history of an expansive and dynamic export industry. Since the beginning of salmon farming in the 1970's, the salmon farming industry in Norway has moved from a local small-scale industry to a global multinational, billion-dollar industry exporting about 90-95% of its production to more than 100 countries all over the world.

Historically, the spot price of salmon has been very volatile. The main cause for high volatility is inelastic short-run supply, which is a consequence of biological factors and a quite long production cycle. The biological nature of the production cycle implies that the desired output does not always meet its target, and therefore there will be periods of over- and undersupply, which cause salmon prices to fluctuate. Unstable supply and volatile salmon price has led to unpredictable cash flows and variability in profits for salmon farmers. Also, uneven supply of salmon from farmers have created distortions in the value chain and affected other agents in the salmon industry.

In this master thesis a mathematical model for optimal harvest time of salmon given different harvest strategies is developed. The most important characteristic of the model is that it enables distribution of harvest over certain months in order to investigate the difference in profits between a non-smooth harvest profile and a smooth harvest profile. In order to ensure solvability, some simplifications of the model have been made, the most important being that seasonal variations are only incorporated in prices and not in production costs and fish growth. Also, an analysis of the salmon farming value chain is conducted based on interviews and information from agents in the industry.

The goal of this thesis work is to investigate the hypothesis that a smoother harvest of salmon provides the salmon farming value chain with additional value. We have used the mathematical model to find the potential loss or benefit the farmer would face by implementing a smooth harvest strategy rather than harvesting only a few times each year. Then in order to investigate whether a smoother harvest of salmon is value-adding or costly, we have conducted an analysis of the salmon farming value chain. The analysis was performed through interviews with different agents in the value chain. We combine our model results and findings from our value chain analysis to decide if smoother harvest indeed generates additional value.

Our findings show that with a smoother harvest of salmon, the salmon farmer loose approximately 9% of potential profits generated from its operations. Hence, a smoother harvest is costly for the salmon farmer viewed in isolation. Also, findings show that the biomass development in the sea is less fluctuating with a smoother harvest compared to

a scenario when harvesting is performed only 2 times per year. Findings show that it is the processors in the value chain that would profit the most from a smoother harvest. Interestingly, results show that retail chains do not experience variations in supply of salmon, indicating that the Norwegian market for salmon are saturated before salmon is exported.

Other interesting findings are the industry concern of high salmon prices and its consequences. We have found that high salmon prices may lead to international competition and higher cost levels, which make higher prices a threat to the industry in the future. Also, with the government not issuing more licenses in the near future, high salmon prices are expected to continue. Through a new regulation proposal, called rolling MAB, the government wants to facilitate a more market oriented production of salmon, and hence more stable supply. We have found that the main motivation behind a rolling MAB is to facilitate more value creation in terms of processing in coastal areas.

Preface

This master thesis is the final step of achieving a Master of Science at the Norwegian University of Science and Technology (NTNU). The degree specialization is Investment, Finance and Financial Management at the Department of Industrial Economics and Technology Management.

This thesis is original and independent work by Anja Graff Nesse and Frida Næss-Ulseth. The thesis looks into the Norwegian salmon farming industry and challenges that the industry is facing today. Moreover, the thesis is a study of value chain dynamics and the use of a mathematical model to explore how different harvest strategies may impact the salmon farming value chain.

Gratitude is given to Peder Strand at SEB Enskilda for inspiration and knowledge regarding the theme, and to Jonas Langeteig at Lerøy Seafood for good inputs and information. We thank Professor Frank Asche at the University of Stavanger, Martin Bryde at the Norwegian Department of Trade, Industry and Fisheries, Tore Holand at Midt-Norsk Havbruk and Trond Storrud at REMA 1000 for good interviews and opinions. Finally we thank Stein-Erik Fleten and Verena Hagspiel for support and motivation.

Trondheim, June 2, 2014

Anja Graff Nesse

Frida Næss-Ulseth

Table of Contents

Chapter 1: Introduction

About 60% of the world's salmon is farmed. Salmon farming takes place in large nets in sheltered quiet waters such as fjords and bays. Since salmon farming requires stable temperatures in the water, only certain areas are suitable for producing salmon. Countries that have this natural advantage are Norway, Chile, Canada and Scotland. These countries contribute to nearly all the farmed salmon in the global market today.

Farming of salmon started at an experimental level in the 1960s, but became an industry in Norway in the 1980-90s. Since then, there has been a tremendous increase in production of Atlantic salmon with a supply growth of more than 600% and the production is expected to grow even further (Marine Harvest, 2013). Salmon farming is Norway's third largest export trade. Today, the Norwegian salmon farming industry employs around 20,000 people and has become the backbone of many coastal communities.

Salmon farming is a capital intensive and volatile business, mainly due to a long production cycle, expensive licenses and equipment. With salmon farming being a biological industry, the industry faces a lot of challenges. One main challenge for the salmon industry is large variations in biomass development, supply and price, which result in risk for both salmon producers and other agents in the salmon value chain. Therefore, the industry has experienced large variations in profitability, manifesting in a large number of bankruptcies and restructuring of the industry.

With no binding capacity restrictions in the last decade, salmon farmers have tried to utilize capacity optimally by maximizing the biological production. This production strategy has resulted in large quantities of salmon supply in the fall and less in the winter and spring. According to numbers from the Directorate of Fisheries, 47% of harvesting has been done between August and November in the last couple of years, while only 5% and 6% of the year's harvest has been done in January and February. This non-smooth harvest profile has led to supply jumps in the market, and hence have affected the price of salmon. A volatile salmon price has led to unpredictable cash flows and variability in profits for salmon farmers. Also, non-smooth supply of salmon from farmers have created distortions in the value chain and affected other agents in the salmon industry.

This thesis will aim to investigate an important issue in the salmon farming industry, namely how different harvest strategies may contribute to additional value in the salmon value chain. Hopefully, it can give insights to important issues in the salmon industry and reveal what industry players considers important for future development of the Norwegian salmon industry.

1.1 Scope of Thesis

The main objective of this thesis is to test if smoother harvest of salmon is value adding or costly. Hypothesis to be evaluated are:

- *A smooth harvest is costly for salmon farmers.*
- *There exists additional value in the salmon farming value chain by adapting a smoother harvest of salmon.*

In order to evaluate this hypothesis the thesis focuses on the following tasks:

1 *Study existing harvest patterns and production dynamics in the salmon industry today.*
2 *Develop a bioeconomic model for the optimal time to harvest salmon and use these results to plan an optimal yearly harvest strategy given batch and smooth harvest.*
3 *Conducting a value chain analysis based on interviews of agents in the salmon farming value chain and other interest groups.*
4 *Compare model results and value chain analysis to support or reject our hypothesis.*

1.2 Limitations

There are certain limitations of approaching the objective of this thesis. The thesis is given a limited time frame of 20 weeks. Accessible resources are provided by the Department of Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU), the university library and companies such as SEB and Nordea Markets. Due to a limited time frame, we have only been able to interview certain companies in the value chain. However, we attended the FHL[1] yearly conference in Trondheim in April where we obtained a wider perspective of the industry through panel discussions and conversations with different people from the industry and the Norwegian government.

With regards to the model, we have made use of articles and books about salmon farming in order to develop a mathematical optimization model. We have built the model from scratch, but due to a limited time frame, we have simplified the model by taking several assumptions in order to generate decent results. The optimization model is implemented in MS Excel.

[1] The Norwegian Seafood Federation (Fiskeri- og havbruksnæringens landsforening, FHL) represents the interests of approximately 500 member companies. The member companies cover the entire value chain both in fisheries and in aquaculture sectors.

1.3 Scientific Approach

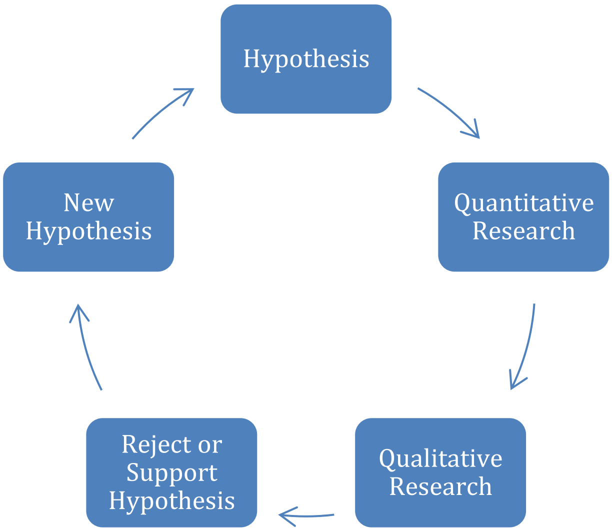

Figure 1: Procedure of deductive research

The research in this thesis is based on a deductive scientific approach, which means that a hypothesis is stated before further research is conducted. The procedure of typical deductive research is given in Figure 1. In the beginning of our work we state a hypothesis that we want to test. We test the hypothesis through quantitative research based on a mathematical model. Furthermore we use qualitative research to gather an in-depth understanding of behavior in the industry investigated. The qualitative method investigates the *why* and *how* of decision making in the relevant industry. This is done with the use of interviews and conversations. We will gather our results from both quantitative and qualitative research in order to reject or support our hypothesis. Finally we will state a new hypothesis based on our results in this thesis.

1.4 Thesis Structure

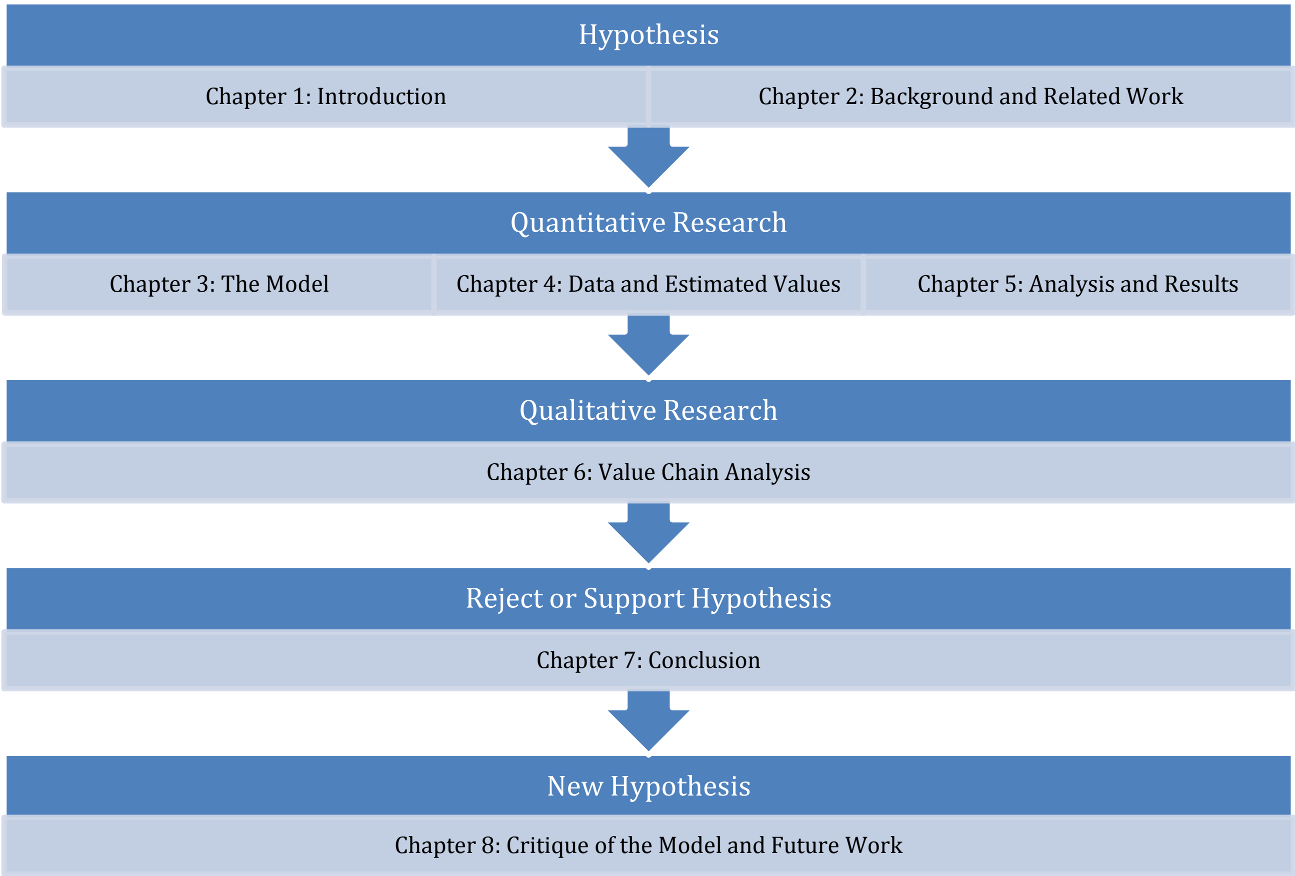

Figure 2: Structure of the master thesis

This master thesis aims to evaluate the hypothesis by dividing the research into four tasks mentioned in section 1.1. Figure 2 shows the outline of this thesis which includes eight chapters, divided into five main parts. The first part presents the scope of the thesis and the theoretical background considered relevant to the hypothesis. An introduction is given in Chapter 1. Chapter 2 presents background and work relevant for the studies done in this master thesis. The second part of the thesis comprises quantitative research. Chapter 3 presents the mathematical model. In Chapter 4 assumptions are presented. Chapter 5 comprises an analysis and results from the model. The third part of this thesis presents qualitative research in terms of an analysis of the value chain given in Chapter 6. The fourth part concerns rejection or support of the hypothesis. This is presented in Chapter 7. Fifth and final part is the suggestion of a new hypothesis. Critique of the model, recommendations for further work and a new hypothesis will be presented in Chapter 8.

Chapter 2: Background and Related work

In the following chapter we will present background information relevant for our model and analysis. In section 2.1, the Norwegian salmon farming industry is presented, and in section 2.2 previous works relevant for our model and analysis is presented.

2.1 Salmon Farming

2.1.1 The Market for Atlantic salmon

About 60% of the world's salmon production is farmed. Supply of Atlantic salmon has more than doubled since 2000 with an annual growth of 7%. The EU and the US are by far the largest markets for Atlantic salmon. However, emerging markets are growing at significantly higher rates than these traditional markets, resulting in increasing demand for salmon.

In Norway, the history of salmon farming is a history of an expansive and dynamic export industry. Since the beginning of salmon farming in the 1970's, the salmon farming industry in Norway has moved from a local small-scale industry to a global multinational, billion-dollar industry exporting about 90-95% of its production to more than 100 countries all over the world (Marine Harvest, 2013). The main reason for the increased production in salmon farming is the productivity growth that has reduced production costs, and made it profitable to sell salmon at lower prices (Asche, 2008). The main markets that Norway is supplying are Europe, Russia and Asia, with Europe being the largest market.

The top ten players in the salmon market in Norway produced approximately 1,183,200 tons of salmon in 2012, contributing to around 60% of the total global supply. According to the Directorate of Fisheries, Marine Harvest represents the largest producer of salmon in Norway with 283 700 tons in 2012, while Lerøy Seafood and Salmar produced 140 000 tons and 114 000 tons respectively.

Historically, the spot price of salmon has been very volatile. This volatility is due to the inelastic supply of salmon in the short-run, which can be explained by the nature of the production process in salmon farming.

2.1.2 The Production Cycle in Salmon Farming

Salmon farming is a biological production process dependent upon biological and environmental conditions. The complete production process is illustrated in Figure 3.

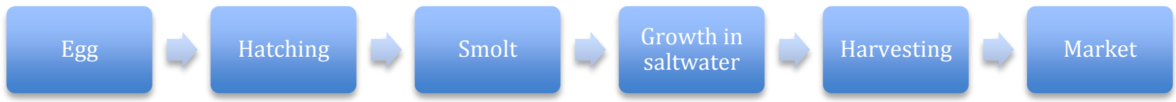

Figure 3: Production process in salmon farming

At a hatchery, salmon eggs are nurtured in freshwater tanks for about 15 months. The resulting outputs from the hatcheries are called smolts, which are young salmon in the stage of its first migration to the sea. The physiological process undergone by salmon to allow them to migrate from freshwater to seawater is called smoltification. After about 15 months, the smolts are transferred to specialized grow-out farms where they are raised to marketable size in sea pens. In the sea pens, the fish are fed for a period of 12-23 months before harvesting takes place. Commercial feeds for salmon can contain as little as 15% fishmeal and 15% fish oil. In other words, raw material of marine origin can be as low as 30%, while the remaining 70% of the feed is from vegetable raw materials (Marine Harvest, 2013). The salmon can be harvested already at a weight of 1-2 kg, but are normally substantially larger. The most common harvesting weight is 3-6 kg, but the fish can be marketed as large as 8 kg.

The biomass develops in correspondence with the seasons. Due to climatic reasons, smolts should only be released to sea during the warmer half of the year. In Norway, this implies smolt release from March to October. The wild salmon spawn during late spring or summer, and normally hatch in January. Due to economics of the production process, the latest month of significant release of smolts to the sea before the summer is May. Thereafter the farmers commence again in September, as shown in Figure 4 illustrating smolt release in Norway over the latest years.

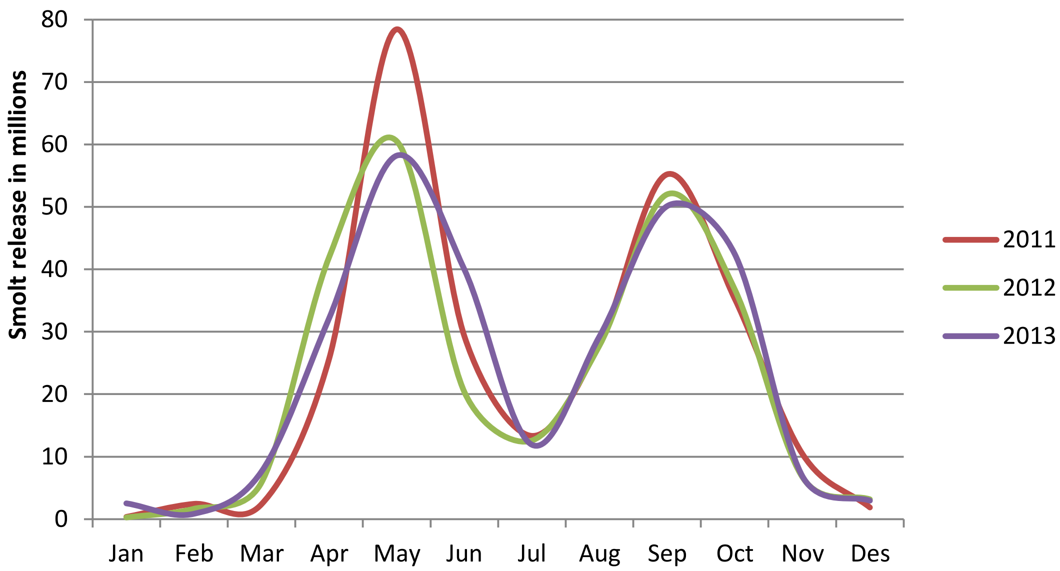

Figure 4: Monthly smolt release (in million) in Norway for 2011, 2012 and 2013

Biophysical factors affect the growth of salmon over the production cycle. Salmon are coldblooded animals and temperature is one of the essential factors for growth. The optimal temperature range for Atlantic salmon is 8-14°C, a temperature level which normally is reached during the warmer half of the year in all production regions. Daylight also contributes to increased growth.

Salmon farming addresses living beings and mortality in the sea pens will be present throughout the production. Under normal circumstances, the highest mortality rate is observed during the first 1-2 months after smolt is released into sea pens. This is due to some of the smolts not having completed the smoltification process before being released into sea. If the smolt-body is not ready to absorb salt at the release time, they will most likely not survive.

After the first months of the seawater phase of production the mortality tends to decline until sexual maturity is approaching. The salmon must be harvested before it reaches sexual maturity, which occurs about 28 months after the fish hatch. In Norway, the salmon have the largest probability of reaching sexual maturity during August-September. Salmon do not necessarily die after they reach sexual maturity, but the quality degradation due to spawning would mean waiting for up to another year before harvesting.

2.1.3 Production Costs

Over time, production costs have been reduced and productivity in salmon farming has increased as new technology and new competence has been achieved. Production costs per kg produced salmon for an average Norwegian company are shown in Figure 5.[2]

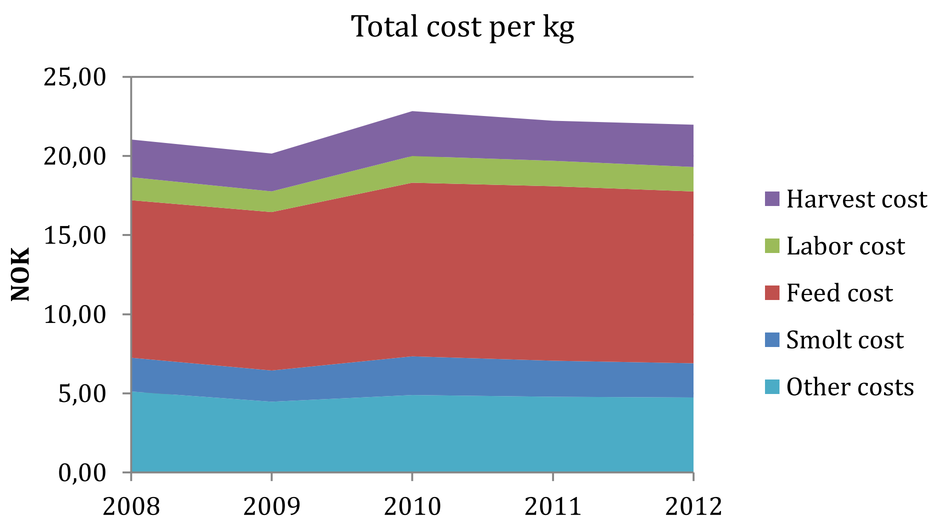

Figure 5: Total production costs per kg from 2008 to 2012

[2] Production cost numbers are found from the statistics from the Directorate of Fisheries, http://www.fiskeridir.no/statistikk/akvakultur.

As illustrated, the production costs have been relatively stable over the last years. Feed accounts for approximately 50% of the total production cost, and hence is the largest cost component. Other significant cost elements are harvesting and smolt costs. Within “other costs” we find expenses related to fish health such as vaccination.

2.1.4 Industry Challenges

Diseases, Sea Lice and Escapes

As salmon farming saltwater facilities are open systems, the production is exposed to the surroundings. The most important biological risk factors are diseases and sea lice. Over the years, the industry has been through several periods with extensive disease outbreaks, but luckily the long Norwegian coastline limits the impact of these outbreaks. In the later years, especially due the development of effective vaccines and improved breeding, the health situation in salmon farming has improved dramatically, and resulted in an average yearly mortality rate of 15% the last decade according to the Directorate of Fisheries. Compared to the late 1990’s where the mortality rate averaged on 20%, the current average mortality rate is a substantial improvement.

One of the most debated issues throughout the history of the industry is sea lice. This problem remains unsolved for the Norwegian salmon farming industry affecting the production. Sea lice infect the skin of the fish, and if not controlled, they can cause lesions, secondary infection and mortality (Torrissen, et al., 2013). The industry is working hard to solve this problem, and in 2010 the Norwegian government stated that no more licenses were to be granted until the level of sea lice is within the limits that the government accepts[3], motivating salmon farmers to prioritize finding a solution to the problem.

Escapes create losses in production due to lost revenue. According to the Directorate of Fisheries approximately 198 000 fish escaped in 2013 from Norwegian salmon farms. For a salmon producer, escapes will in general be a less serious problem than mortality caused by diseases or sea lice.

Governmental Regulations

In most countries with salmon farming industry, Norway included, governments impose regulations on farming activity. Environmental- and consumer concerns have been the main motivation for the Norwegian government to impose stricter regulations in the salmon farming industry. According to the Norwegian Ministry of Trade, Industry and Fisheries, the purpose is to ensure food safety and maintain a profitable industry within the limits of sustainable development. In Norway, the Ministry of Trade, Industry and Fisheries, the Directorate of Fisheries, the Norwegian Food Safety Authority, the Norwegian Coastal Administration and regional governments all regulate the industry.

[3] The Ministry of Trade, Industry and Fisheries –” Strategy for an environmentally sustainable aquaculture industry”, published in 2010.

The production capacity and potential for further expansion is mainly decided by the government. The Norwegian government issues producing licenses, the key prerequisite in order to produce salmon, and hence control the total capacity available in the industry. A company or group may have several licenses, but there is a limit of 40% of the total number of licenses in the industry that one single company may operate. In 2012, there were 1040 licenses all together in Norway, operated by 164 companies. Since 1982, new licenses have been awarded only in limited numbers in 1985, 1988, 2001, 2002 and 2009. The last allocation of licenses was in 2013, where the government issued 45 green licenses, which are licenses that require new and "greener" production methods.

In 2005, the government introduced a regulation called "Maximum Allowable Standing Biomass" (MAB), which states the maximum volume of live fish present in the cages at any time. The current MAB system gives a maximum allowable biomass at 780 tons per license for most farms. Exceptions are in the north of Norway where the biomass limit is higher (945 tons in Troms and Finnmark) due to local growth conditions for the fish. Also, a company with more than one license can shift MAB between them.

Since the biomass grows quickly during late summer and fall, the companies are often forced to harvest part of the standing biomass which exceeds the MAB level.

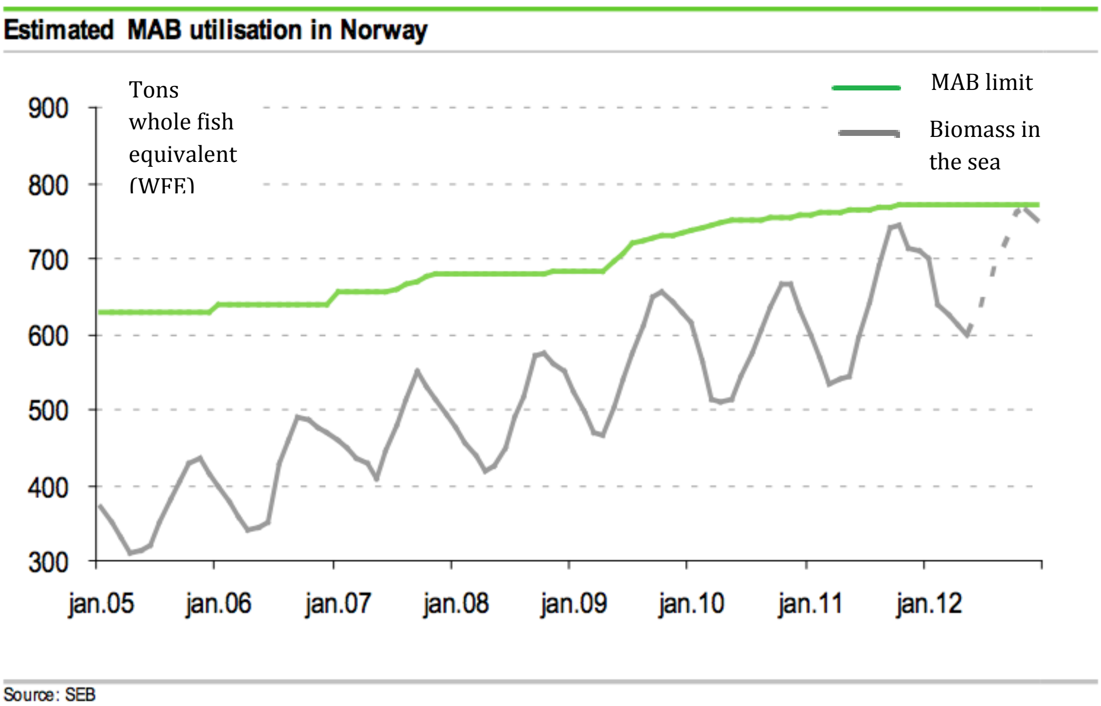

Figure 6: Estimated MAB utilization in Norway

As Figure 6 illustrates, in 2012, the producing companies experienced that the total biomass reached the MAB limit (Strand, 2014), forcing the farmers to harvest the excessive fish in the sea. Harvesting due to the MAB limitation gives a non-market oriented supply, and has created discussion to whether this regulation could be implemented differently. The government has proposed a “rolling MAB”-scheme, where the MAB limit is such that the average biomass over a year should not exceed a given figure. The average MAB would allow the producers to maintain a larger quantity of salmon in the sea pens during late fall and winter, at which point the market is usually undersupplied and prices are high.

The Salmon Price

The salmon price is one of the most important factors affecting profitability in the industry. Salmon prices are determined, like other prices, by the law of supply and demand.

Short term price volatility

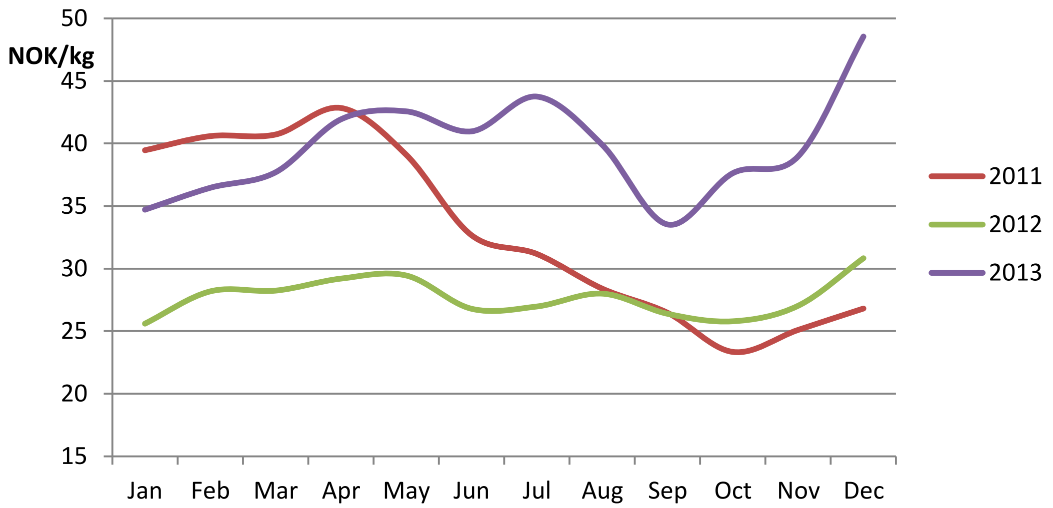

Figure 7: Salmon prices for 2011, 2012 and 2013 in NOK/kg

Figure 7 shows the salmon price over the last years illustrating large fluctuations from month to month. The main cause for high volatility is inelastic short-run supply, which is a consequence of biological factors and a quite long production cycle (Andersen, et al., 2008). The biological nature of the production cycle implies that the desired output does not always meet its target, and therefore there will be periods of over- and undersupply, which cause salmon prices to fluctuate. The facts that fish growth is individual and not a linear function over time combined with two main releases of smolts per year, results in a seasonal pattern to the availability of salmon in the market, (Asheim, et al., 2011). Figure 8 show the harvest of salmon in thousand tons for 2011, 2012 and 2013.

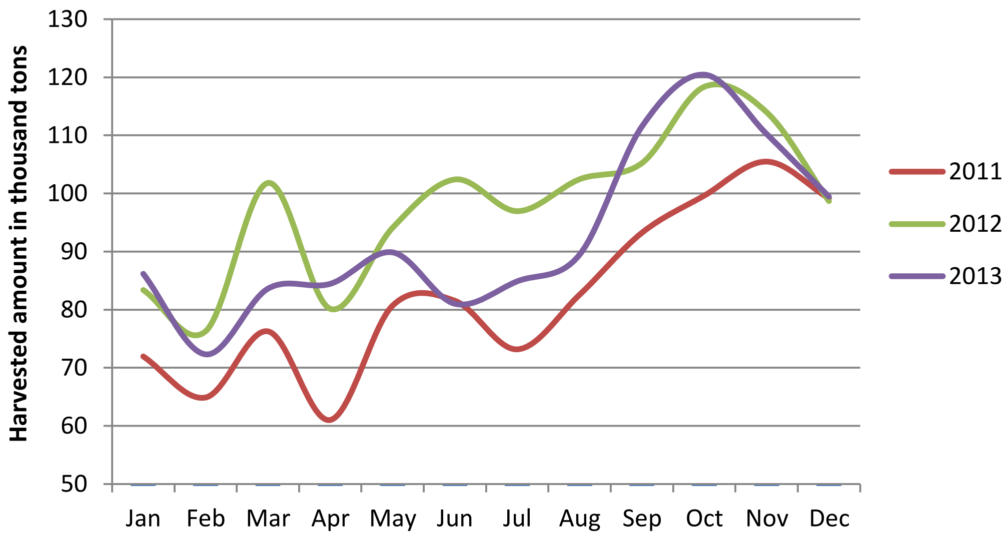

Figure 8: Harvested salmon (in thousand tons) for 2011, 2012 and 2013

The harvest profile demonstrated in Figure 8 is a result of the limited effect the price has on the supply in the short-run, making the salmon farmers "price takers" in the market. For this reason, volatile prices make the timing of harvesting an important factor for profitability.

In order to partially mitigate the price risk arising from spot sales of salmon, many salmon farming companies have entered into financial salmon contracts such as forward and futures at the regulated market place Fish Pool. The use of forward and futures enables salmon producers to secure a price that they will receive on future production. Fish Pool is a reference market with the best available information regarding future contract trading, and their forward prices are used as a benchmark in the industry.

Long term price volatility

Historically, the industry has experienced the following cyclicality: When prices are high, the farmer seeks to increase profits by increasing production. This results in prices declining due to oversupply of salmon. Then the farmer might choose to reduce intensity of production due to low profitability, which after another production cycle leads to an undersupplied market and price increase. Since approximately the entire industry follows this strategy, the resulting effect on the price has gotten very large. Changes in supply have been explained by over 85% of the changes in the salmon price from 2002 to 2011 as shown in Figure 9. Therefore, studying the supply has been very important to make a price forecast. The supply or the future harvest quantities are highly indicated by the standing biomass in the sea, feed sales and smolt release. Further indicators are the sea water temperatures, disease outbreaks and vaccine sales. The supply/demand equilibrium from 2002 to 2011 has been about 6-7%. This is demonstrated in Figure 9.

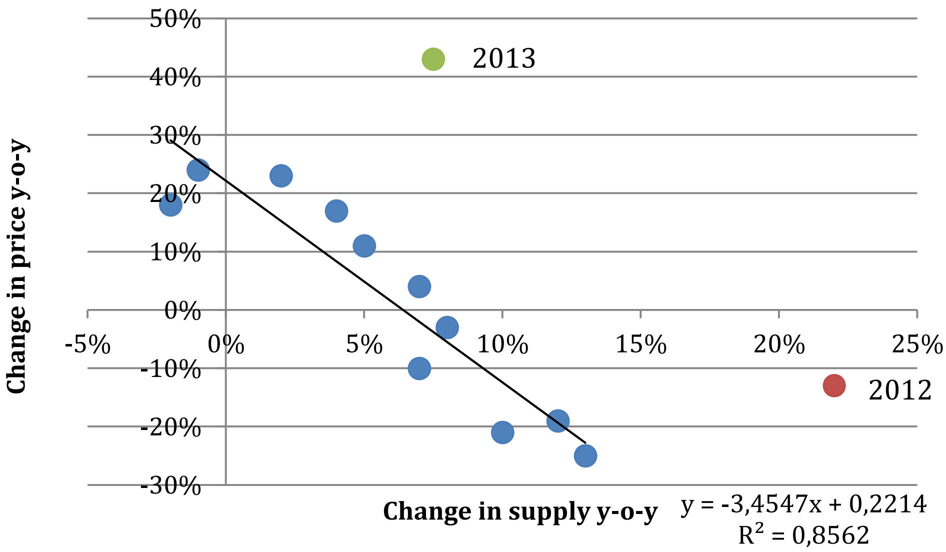

Figure 9: Changes in supply and price y-o-y from 2002 to 2013

In 2012, the salmon market experienced large supply of salmon, which resulted in a price drop that stimulated demand since salmon became relatively cheaper than competing sources of protein. Additionally, innovations in processing have made salmon products more convenient for the consumer, which has contributed to increased consumption. With capacity restricted, the industry was not able to meet demand during 2013 resulting in an average price of 40 NOK/kg. Since this capacity level will remain until the 45 new licenses granted in 2014 are realized as supply in the market, the industry will face difficulties meeting demand. In summary this results in limited supply increase in a market with continuously growing demand, making the price shift from being supply to demand determined. The key question and concern is if demand destruction will take place. How price sensitive is the consumer and at which price level will demand begin to decrease?

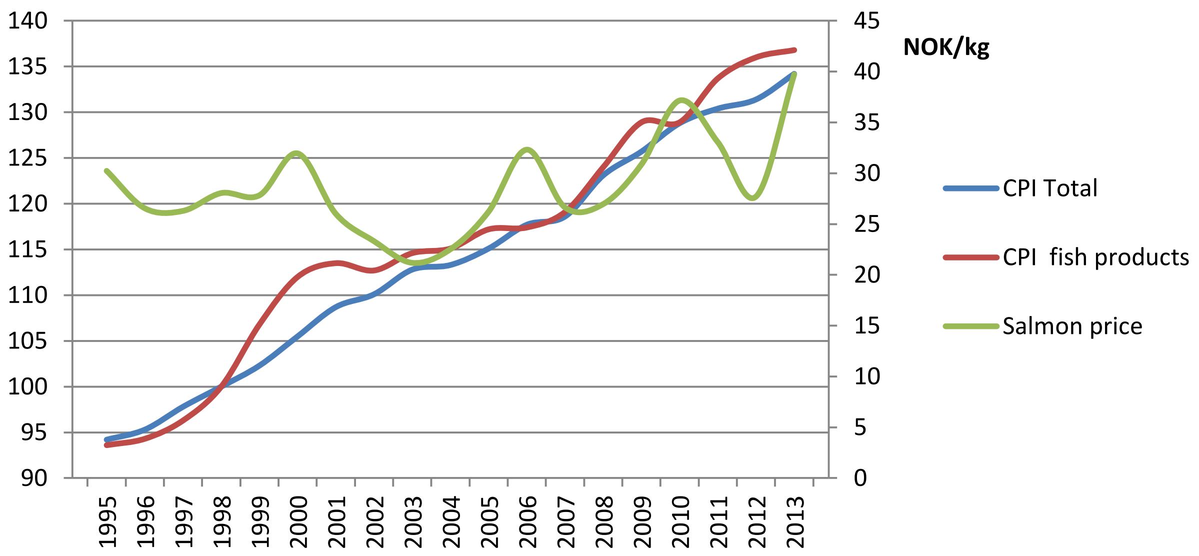

Figure 10: CPI total, CPI for fish products and the salmon price from 1995 to 2013

Figure 10 shows the salmon price relatively to the Norwegian consumer price index (CPI) in the period 1995 to 2013. The data is collected respectively from Index mundi and Statistics Norway. The farmer got about 25-30 NOK/kg 20 years ago, approximately the same price as in 2012. The main reason for this is the adaption of new technologies and learning, which has made the industry able to reduce the costs of production dramatically. In the long run, this has been the key to maintaining high profits in the producer part of the value chain. Also, in the Norwegian market, salmon has gotten relatively cheaper as the real earnings of the people have increased considerably during this period. Additionally, the salmon price in Figure 10 illustrates the industry cyclicality due to the price and supply dynamic explained above.

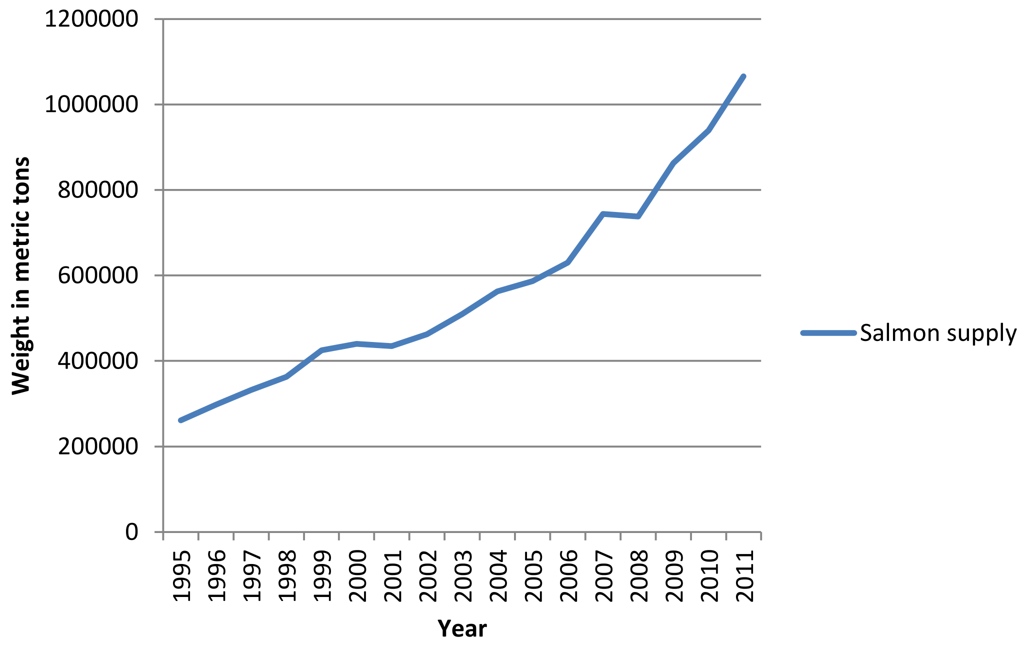

Figure 11: Salmon supply in Norway from 1995 to 2011

As Figure 11 shows, the Norwegian supply of salmon has increased considerably over the last decade. Over the years, the salmon price has been determined by supply and not demand, which explains why the current salmon price level is approximately equal to the price level found in 1995, as seen in Figure 10. Today however, the Norwegian salmon industry experiences a shift from a supply-driven salmon market to a demand-driven salmon market because there are no new licenses and hence capacity available for the farmers. The future salmon price is therefore strongly determined by the demand for salmon and the buyers' willingness to purchase salmon at a higher price level than seen in the last couple of years.

2.1.5 Salmon Farming Value Chain

Industry Structure

After the Norwegian authorities relaxed their regulations on horizontal integration in salmon farming in the beginning of the 1990s, a merger and acquisitions process started and several hundred firms were integrated into larger companies. In general, the salmon farming industry consist of three different types of companies:

1. Large, multinational vertical and horizontal integrated companies with a turnover of several billion NOK
2. National/regional mid-size partly vertical integrated companies with a turnover of several hundred million NOK
3. Smaller local companies with a turnover of some ten times million NOK

The change in industrial structure also led to an industrialization of the salmon value chain. The size of the companies and their interest and ownership in other parts of the value chain varies. Larger corporates such as Marine Harvest, Lerøy and Salmar have shown more interest in controlling several parts of the value chain.

The value chain

The value chain mainly consist of suppliers of equipment, inputs and services, salmon farmers, primary processors, secondary processors, distributors and retailers.

Suppliers of essential inputs to salmon production are suppliers of smolt and feed. Vertical integration has led to a large amount of the farmers producing the majority of smolt "in-house". During the last decade, the feed industry has become increasingly consolidated, with now three main producers controlling the majority of salmon feed output, namely BioMar, Ewos and Skretting. The feed producers are exposed to the prices of raw materials, which are fish oil, fishmeal, soy and wheat.

Other suppliers to the salmon value chain are suppliers of equipment and services. Norwegian suppliers of equipment such as net pens, feeding machinery and surveillance systems, has contributed to the development within aquaculture since the 1980s. Since a great part of the industry innovation takes place here, their role in the reduction of production costs in salmon farming has been significant. AKVA Group is one of the leading players within technology deliveries to the salmon industry.

The farming companies' core activity is to grow the salmon from smolt release to harvest, and then slaughtering the fish. At the slaughterhouses, the salmon is euthanized, gutted and packed in cooling boxes. Then the fish is shipped abroad or delivered to the Norwegian processors. Companies that are vertically integrated often include several activities such as production of smolt, farming and processing. The largest players within farming are Marine Harvest, Lerøy, Salmar and Cermaq. Normally the farmers deliver head on gutted (HOG) salmon to the subsequent stage in the value chain.

Processing of HOG salmon includes primary- and secondary processing. Primary processing, normally fileting, is usually performed in Norway, while secondary processing, such as smoked salmon, normally takes place in Eastern Europe, mainly in Poland. The largest players within processing are Morpol and Labeyrie.

The processors usually buy fish on the spot market, and must therefore handle variations in prices, volumes, sizes and delivery times. Hence, their key input factor is exposed to risk. From the moment the fish is taken out of the sea, its durability is 2-3 weeks, which gives the processors time pressure. When processing is completed, the product is sold to retailers, foodservices or distributors, normally through contracts. Most of the salmon are sold as fresh fish, while about one third is sold as frozen fish.

The EEA-agreement gives free trading of most goods, expect fish. The Norwegian processing industry is therefore affected by customs duty when exporting salmon products to the EU, which is the largest market. In general, customs duty increases with increasing degree of processing.

At the downstream end of the supply chain, large retail chains connect the salmon products to the final customer. Requirements in terms of timing, regularity, quantity and quality are of high importance in this final stage of the value chain. Retailers now purchase 60-90% of the salmon in many European countries. Examples of large retail chains in the international market for salmon are Carrefour, Wall Mart and Lidl. On a national level, REMA 1000 and NorgesGruppen are the largest players.

2.2 Related Work

This section presents a review of existing literature concerning optimal harvest time and harvest strategies in salmon farming, and also relevant literature concerning salmon prices and biomass development in the sea. In general, models designed for estimating optimal harvest time, usually called bioeconomic models, seek to maximize profit or minimize cost subject to a set of biological conditions and production constraints. This is the type of model we choose to apply in this thesis.

A bioeconomic model is composed of a biological model describing a production system, and an economic model relating the production system to market prices and resource constraints. The biological model we study is composed of two essential building blocks, a fish growth expression and a population dynamic model. The economic model includes a revenue function and a cost function.

Forsberg (Forsberg, 1999) develops a bioeconomic model that considers two management strategies for harvesting size-structured fish cohorts. The first strategy allows the fish farmer, at any time, to size-grade, harvest and sells the most profitable fish sizes from the standing stock, called graded harvesting. The second strategy allows the fish farmer to harvest and sell a fish batch with similar size distribution as that of the standing stock, called batch harvesting. Batch harvesting is very similar to the harvesting strategies demonstrated in our model, where size classes do not have an impact on how many fish that is harvested. Forsberg has developed two fish growth models integrated in a multi-period linear programming model that optimizes the harvest outputs for each of the two strategies. By identifying and adding several production constraints for commercial salmon farming, Forsberg evaluate the two management strategies and the resulting profitability of the two strategies. In the paper, a single average Norwegian salmon farm producing about 700 tons of fish is considered as a basis for the model and the constraints. In the paper, it is assumed that smolt is transferred to seawater between May and October, which is assumed in our model as well. Furthermore, due to the paper being written in 1999, Forsberg restrict the production by feed quantity regulations, equivalent to the maximum allowable biomass that restricts the production today. For the model to be applicable today, the feed quantity restriction would be replaced by a maximum allowable biomass restriction. The fish growth model is developed from population dynamics theory, and contains equations describing how fish of different sizes grow over the production period. To incorporate sales income, Forsberg use a market price vector illustrating the market price for different size classes of fish, and also only variable costs in the production is considered in the model. We make use of the same assumption in our model, that only variable cost is considered when finding an optimal time to harvest salmon. In the optimization model the managerial decision center on the determination of the best time sequence for harvesting the various fish cohorts, and the objective for the fish farmer is to maximize the net present value from the operation. Results show that it is more profitable to size-grade fish prior to harvest compared to harvesting a batch of fish with similar size distribution to that of the standing stock. However, size-grading fish may be costly, and requires more resources than batch harvesting, which is not accounted for in the article. Furthermore, it is clear that the different harvest operation constraints have a significant impact on the optimal harvest plan and the resulting profits. The profitability decreases with increasing numbers of binding constraints, with losses in profitability mainly caused by declines in harvested biomass due to operation constraints. The model outputs demonstrate that profitability of a fish farm would be substantially increased if fish were graded prior to harvesting, with the results suggesting that a 10-15% increase in profits can be expected with graded harvesting compared to batch harvesting. An even more important result from the paper is that graded harvesting not only is more profitable compared to batch harvesting, but also that graded harvesting lead to a smoother harvest of fish distributed over a longer time period than for batch harvesting.

In his study, Bjørndal (Bjørndal, 1988)presents a model of optimal harvesting of farmed fish. Bjørndal analyzes the effects of economic and biological parameters on optimal harvesting. In a specified biological model of a yearclass of fish output price and costs are added to constitute a bioeconomic model. Bjørndal use a Beverton-Holt recruitment model to model population dynamics in salmon farming. Furthermore he incorporated feed, release and insurance costs to develop both separate bioeconomic models and combined. Bjørndal has also developed models for selective harvesting and optimal rotation problems for fish farming. This work has been extended by Bjørndal and Asche (Asche & Bjørndal, 2011) to a complete study of the aquaculture industry. They analyze the main factors that have created the salmon aquaculture industry, as well as opportunities and challenges facing it. Moreover, Asche and Bjørndal develop a theoretical approach to the optimal harvesting time for farmed fish. They develop a biological model by adapting a Beverton-Holt model to find the number of fish in one cohort at all times. Also, fish growth is incorporated in the model as a function of weight, density and feed quantity. Furthermore, a bioeconomic analysis is undertaken with the objective to find the optimal rotation time for one cohort of fish. Results show that the individual fish reaches its maximum weight at a later point in time than the entire cohort. Also, as the fish price increases with the weight of the fish, the maximum biomass value is reached at a later point in time than the maximum biomass weight. Also, the optimal harvest time is evaluated for different interest rates, showing that the optimal harvesting time is relatively insensitive to changes in the interest rate. Another key finding is that the harvesting time is only to a small extent influenced by variable costs. Asche and Bjørndal also analyze production planning in a salmon farm. The analysis makes use of a discrete time model that is updated once a month with respect to important variables such as the number of fish, growth, feeding and mortality. Furthermore, they look at the short-run decisions related to a single release of fish on an existing farm after the smolts have been purchased. Findings show that it is optimal for the fish farmer to harvest all fish in the same month. However, the authors emphasize that with other assumptions it might be optimal to spread harvesting over time. This could be due to differences in growth, seasonal price variations, or a desire to spread risk. Moreover, supply may have less impact on price when spread over a longer period. However, results show that harvesting over 4 months, with the maximum value found in July to October, gives a slightly lower maximum present value than harvesting all fish in 1 month. Asche and Bjørndal argue that spreading the harvest over a longer period might enable the farmer to undertake all harvesting with the normal labor force, whereas hiring additional labor is required when harvesting in a short period. As such, reducing costs by spreading harvesting over time may by itself make smoother harvest an optimal policy if the farm in question has the facilities available.

Cacho (Cacho, 1997) presents information on model building and use, and defines concepts of systems and bioeconomic modeling. In the paper, a simple optimal control model, applied to harvesting and feeding decisions, is used to illustrate the numerical solution of dynamic optimization problems. Cacho defines systems modeling and presents different models related to aquaculture such as fish growth models, pond management models, farm management models and economic models. Furthermore, Cacho defines a bioeconomic model consisting of a biological model, which describes the production system, and an economic model, which relates the production system to market prices and resource constraints. In the paper, Cacho has developed an optimal control model with the objective to determine the feeding and harvesting trajectories through time that maximizes profits over a growing cycle. The control problem is subject to a number of biological constraints such as growth rate of fish and number of fish in the farm. Mortality among the fish is also considered. Finally, Cacho solves the optimal control model by using two nested iterations to find a numerical solution. Cacho concludes that the suitability of bioeconomics as a tool for interdisciplinary co-operation and its potential ability to help design more efficient research programs is one of its main strengths. Cacho emphasizes that modeling is not a substitute for field research, but is an ideal complement to field and laboratory research efforts with a need for close co-operation between modelers and field researches.

Løland et al (Løland, et al., 2011) construct a statistical model to forecast the stock of Norwegian farmed Atlantic salmon. The authors aim is to present a prediction model for regional and national standing biomass, which can be used to investigate consequences of changing production strategies. In the article, a model is developed to provide predictions of future biomass of Norwegian farmed salmon and to perform "what-if" analysis to be able to explore the impact of varying scenarios for stocking and slaughtering. The model is related to standard size-structured models, such as the one Forsberg developed in his paper mentioned earlier in the text. The model is based on the number of fish in each mass class, and computes the number of fish growing into the next mass class the next month and the fish remaining. Also, the number of fish stocked, lost, slaughtered and wasted as well as sea temperature is incorporated into the model. Parameter estimations are based on monthly data from 2002 to 2007. The model contains five sub models for monthly values of standing stock distributed among mass classes; stocked number of fish, loss, slaughter and waste, and sea temperature. By analyzing four mass classes in Mid Norway, results show that the relative fish growth decreases along with increasing mass and has a maximum when the sea temperature is around 11-12 °C. By replacing simulations from one or more of the sub models with certain scenarios for those quantities, the model can be used for investigating consequences of changing production strategies. The authors emphasize the strong seasonality in the production that force the amount of slaughtered fish to be driven by supply and not by demand, and investigate if other production strategies can give a more stable production over time. By combining a stocking scenario where all farmed salmon were stocked during the spring with a slaughtering strategy where an equal amount of fish is slaughtered each month, the model illustrates how the biomass development would look like with an alternative production strategy. Results show that when allowing for a stocking strategy, a flat slaughtering strategy is possible with quite few consequences for the standing stock of salmon.

Asheim et al (Asheim, et al., 2011) investigate the short-run supply elasticity of salmon with respect to the price of farmed salmon. In the article, an econometric model of salmon supply is estimated exploiting monthly data on Norwegian salmon aquaculture, which is used to examine factors that may influence the supply of salmon. The production process of salmon farming is presented, and different harvest incentives discussed. Important findings from the model are that sea temperatures seem to have no statistically significant effect on harvest supply. We apply this in our model, assuming that fish growth is independent of sea temperatures. More important is the biomass of live salmon in the previous production month, illustrating that an increase in biomass in the previous month leads to a higher harvest of salmon. In other words, excessive biomass due to fish growth triggers harvesting. Also, results show that there has been a significant influence from different innovations on the harvest supply of salmon during the data period, which are observations from January 1995 to December 2007, a total of 168 observations. Other findings illustrate that the sea temperature has more influential effect on the farmers' total biomass of live fish rather than on the harvested supply. Important takeaways from the article is that supply has shifted over time due to innovations in several areas, and that the price of farmed salmon has a limited effect on supplied quantity, giving highly inelastic short-run supply elasticity. Also important is that the price of feed, with feed being the most important input in salmon farming with a cost share of around 60%, has no significant effect on the short-term harvest supply. Another key takeaway is that in the short run, the price of salmon has limited influence on salmon supply, as it is largely determined by the existing stock of live salmon in the sea and exogenous factors in the market. However, in reality salmon price provides farmers with strong incentives to adjust supply. But as the time horizon moves from months to years, the importance of biological and other constraints is reduced, and salmon price becomes more influential as a determinant of salmon supply. The authors conclude that the biomass and seasonal factors are the main determinants of shifts in salmon supply in the short term.

Andersen, Roll and Tveterås from the University of Stavanger (Andersen, et al., 2008) investigates the salmon industry's short run and long run supply responsiveness separately. Findings show that there is close to zero own-price supply responsiveness in the short run, but in the long run supply of salmon becomes more elastic, which explains the observed cyclical profitability in the salmon farming industry. In the paper, a restricted profit function for Norwegian farms is estimated based on data from 1985 to 2004, deriving demand and supply elasticity. Results indicate that salmon producers have limited possibilities to respond to price changes in the short run; hence the supply elasticity is close to zero. In the long run, the supply elasticity increases, indicating that production becomes more flexible. Also it is found that supply is more responsive to input prices in the long run, where feed in particular becomes a restriction on output, as a 1% increase in feed price will reduce supply by 0.8%. This suggest that the introduction of feed quotas, which have been applied in Norway some years back, is a relatively effective tool when one wishes to limit production. Concluding remarks note that delayed response in supply may cause an overshooting in production in the long run, which will depress prices, causing a fall in profits. Therefore, the observed volatility in industry profits might be explained by the combination of high responsiveness in the long run and limited responsiveness in the short run.

Changes in the regulation regime of salmon farming and in particular a more market oriented production of salmon are discussed in the industry today, but there is high uncertainty in what the regulatory framework will look like in the future. The government has appointed a group of experts to evaluate different regulation regimes and its consequences.[4] Among the different proposals from the expert group is a rolling MAB regime with the aim of giving the farmers more flexibility in the production and to facilitate a smoother harvest of salmon. This emphasizes the relevance of the topic we are discussing in this thesis. Furthermore, the Norwegian salmon farming industry is a large and important industry for Norway, and there are many interest groups to consider. This implies that harvest strategies are important to investigate not only with regard to the farmer, but with regard to other interest groups as well as we will see later in this thesis.

[4] The government has appointed a selection of experts led by Professor Ragnar Tveterås at the University of Stavanger that will use this year (2014) to propose new policies for the salmon farming industry.

Chapter 3: The Model

In this chapter we will give an introduction of the objective and scope of the model developed in this thesis, and a thoroughly presentation of the model.

3.1 Model Introduction

In this thesis we want to test the hypothesis that smoother harvest of salmon is more costly than batch harvesting, and that the lost value can be regained in other stages of the value chain.

3.1.1 The Model Objective

The model objective is to find the initial harvest month that maximizes the profit[5] generated from harvesting a cohort of fish given different biological and economic constraints.

3.1.2 The Model Scope

We have developed a discrete model that derives the optimal production month to initiate harvest after the release of one smolt generation. The model takes into account biological factors such as fish growth and natural mortality, and also economic factors such the price of salmon, different production costs and a discount rate. To be able to analyze the effects of a smoother harvest we find the optimal time to start harvesting given three different harvest scenarios. These include harvesting over one, three and six months, all at a sequential rate after harvest initialization. After finding the corresponding value of the profit gained from each of the harvesting scenarios, we will show the different production planning strategies these scenarios can lead to. The differences in profits gained by smooth- and non-smooth production planning will give us an indication of the value gap between these harvesting strategies.

To facilitate the modeling, we have made some assumptions. First of all, we will not regard the first part of the production cycle as relevant for harvesting since the fish is too small. Hence we analyze a time horizon of 12 to 23 months which is when the fish are reaching harvest-ready size, and harvesting becomes relevant. Forsberg (Forsberg, 1999) use a time window of 14-24 months from smolt transfer to harvesting. Such a time window was probably reasonable in 1999 when Forsberg developed his model, but

[5] In the model and the analysis, profit is in terms of profits gained after accounting for the largest variable cost components; feed costs and harvesting costs. Other expenses are not accounted for as we are interested in the difference between profits from different harvest scenarios, and not the scale of the total profits.

today the production cycle is slightly shorter, usually between 12 and 23 months which is what we have selected.

Secondly, seasonal variations are considered not to have an impact on the harvest decision, just like Asheim et al (Asheim, et al., 2011) describes in their paper. Therefore, we will apply a fish growth function independent on the release month of the smolts. Even though there are several of academic papers, for instance Løland et al (Løland, et al., 2011), that includes a growth function and harvesting dependent on the seasons, there is no consensus regarding the level of impact from factors such as sea temperature and light on harvesting. Considering these disagreements and the fact that climate conditions change between geographical locations and from year to year, we will only model fish growth dependent on the production time. Since the feed cost depends directly upon the growth, the costs will accordingly also be independent upon the seasonal variations.

The MAB limit is not a restriction in our model. The reason for this is that we are interested in the difference in value between the harvesting scenarios. Restricting this problem by the MAB limit would only give us a production scale shift, but the relative difference would still be the same. On the other hand, if we were to optimize the amount of smolt to release, the MAB limit would be a crucial restriction.

We assume that the only biological risk affecting the production is natural mortality in the sea pens. Unexpected events such as major disease outbreaks or escapes are not counted for. We assume this because the model is based on production of fish in Norway, where the long coastline hedges the farmers against against major disease outbreaks. Also, escapes are not counted for because, as mentioned in Chapter 2, escapes pose a significantly smaller risk to the farmer than natural mortality, and should not be accounted for when optimizing the harvest strategy.

Finally, only the most important variable production costs are considered. Apart from feeding and harvesting costs, the other costs such as vaccination and labor costs, are assumed to occur no matter when harvest takes place, and is therefore not of large interest in our model. Fixed costs are neither taken into account, as they have no influence on the optimal harvest decision. Again, it is the relative difference between the scenarios that is of interest, and the cost that remains constant will not impact our results.

3.2 Presentation of the Model

The objective function of the maximization problem is given by,

$$\max_{T_1}\left\{\sum_{t=T_1}^{T_n}\frac{(p_t - C_h)B_t\alpha_t}{(1+r)^t} - \sum_{t=1}^{T_n - 1}\frac{C_f\varphi(w_t - w_{t-1})N_t}{(1+r)^t}\right\} \tag{3.1}$$

The objective is to maximize the net present value of profits with respect to T_1, which is the time when the farmer starts to harvest the fish. The time t is incremented in monthly time intervals. The production process lasts from time zero to T_n, which denotes the last month of harvesting. The number of harvest events is denoted by n. The biomass in the sea at time t is denoted by B_t, and is the product of the number of fish N_t in the sea at time t and the individual fish weight w_t at time t. In the model, α_t denotes the amount of fish harvested each month.

The price of salmon at time t is denoted by p_t. The harvesting cost denoted by C_h only occurs in the months when harvest is done, which are between the first harvest month T_1 and the last harvest month T_n. The discount rate is denoted by r and is assumed to be constant. The immediate revenues are discounted back to the time of the smolt release. The first sum of equation (3.1) illustrates the present value of the net revenues realized during the harvesting months.

The second sum of equation (3.1) accounts for the feeding cost. Feeding of fish starts in the first month of production and lasts until right before it is harvested, i.e. at time $T_n - 1$. The feed cost per kg is denoted by C_f and φ denotes the feed conversion ratio, which is the amount of feed it takes to grow a kilogram of fish. The feed conversion ratio multiplied by the fish growth, $\varphi\ (w_t - w_{t-1})$ is the quantity of feed consumed by one individual fish during month $(t-1)$ to t. To get the cost of feeding the entire cohort during one month, the feed conversion ratio and the fish growth is multiplied by the number of fish at a given time t, N_t and the feed price per kg C_f. The feed costs are discounted by r each month back to the smolt release date.

The farmer also faces a set of restrictions to the production. The biomass in the sea is given by,

$$B_t = w_t N_t \tag{3.2}$$

It is just the total amount of kg fish in the sea, which is the weight of the individual fish w_t mulitplied by the number of fish N_t at that time. The biomass can never be less than zero. The number of fish in the net pen, which the biomass is strongly dependent upon, will change over time as a result of three fundamental rates; mortality, harvest and growth. While mortality and harvesting represents a decrease in the total biomass, growth represents a rise in the biomass.

We describe the development of one fish population through time by a Beverton-Holt model. The Beverton-Holt model is a classic discrete-time population model which gives the expected number of individuals in a generation as a function of the number of individuals in the previous generation. A Beverton-Holt model is commonly used to present the rate of change in the numbers of fish in one cohort in bioeconomic models, (Asche & Bjørndal, 2011). For instance, Bjørndal (Bjørndal, 1988) and Cacho (Cacho, 1997) use the Beverton-Holt model in modelling aquaculture systems, while Skonhoft (Skonhoft, 2012) make use of the Beverton-Holt model in describing wild salmon recruitment in small rivers.

According to the Beverton-Holt model, the following applies,

$$N_0 = R$$

At time zero , the initial number of fish in the sea pen, denoted by N_0, is equal to the amount of smolt released into the sea called recruits, which is denoted by R. We assume homogeneity among the released fish, that is the growth function is equal for all the fish, since they are farmed out of the same smolt batch in the same sea pens under the same feeding regime. An extended mathematical representation of the Beverton-Holt model is illustrated in the Appendix.

According to the Beverton-Holt model, the number of fish can be expressed as,

$$N_{t+1} = N_t(1 - m_t)$$

in a discrete setting. By adapting the Beverton-Holt model in a discrete setting and allowing for the number of fish to decrease with a harvest rate, the number of fish in the sea in month $t + 1$ in our model is given by,

$$N_{t+1} = \begin{cases} R & t = 0\,, \\ (1 - \alpha_t)(1 - m_t)N_t & 0 < t < T_n - 1\,, \\ 0 & otherwise. \end{cases} \tag{3.3}$$

The number of fish in the sea is dependent on both mortality and the harvested amount of fish. The mortality rate is denoted by m_t, and α_t is the percentage of the total amount of fish that is harvested at time t. N_t denotes the number of fish in the net pen at the beginning of each month. At time zero, the number of fish is equal to the initial amount of fish released into the net pen, denoted by R. From this point and forward, the number of fish will only decrease due to the mortality and harvest. From one month to the next, $(1 - \alpha_t)(1 - m_t)$ is the remaining percentage of fish in the net pen after mortality and harvest. Hence, the number of fish will only decrease from the smolt release until the final harvest event. After the last harvest at time T_n, there are no fish left in the net pen. We assume that for each month, fish growth and losses from mortality in the production occur after harvesting takes place in that particular month. Furthermore we assume that all harvest in one month is done in a short period of time, for instance in one day, so that growth and mortality do not affect the biomass during harvesting.

The amount harvested of the total standing biomass each month is given by,

$$\alpha_t = \begin{cases} 0 & t < T_1 \,, \\ \dfrac{\alpha_{t+1}\dfrac{w_{t+1}}{w_t}(1-m_t)}{1+\alpha_{t+1}\dfrac{w_{t+1}}{w_t}(1-m_t)} & T_1 \le t < T_n \,, \\ 1 & t = T_n. \end{cases} \tag{3.4}$$

This constraint represents a distribution problem, since we want to harvest the same amount biomass in kg at each harvest event. In Equation 4, α_t denotes the amount of the total standing biomass harvested each month, and restricts the harvest to be of equal quantity at each harvest event. Naturally, α_t is only relevant for the months where harvest takes place. Since the first harvest happens at $t = T_1$, the amount harvested before T_1 is zero for all t. At the final harvest event T_n, the sea pen is completely emptied and the harvest is therefore equal to 100% of the the standing biomass. In the prior months, the amount harvested is derived from a relationship between the weight and the mortality rate. At every harvesting event, we extract a given biomass quantity K_{T_n},

$$K_{T_1} = w_{T_1} N_{T_1} \alpha_{T_1}$$

$$K_{T_2} = w_{T_2} N_{T_2} \alpha_{T_2}$$

$$\vdots$$

$$K_{T_n} = w_{T_n} N_{T_n} \alpha_{T_n} \tag{3.5}$$

Equation (3.3) expresses the number of fish in one population between the releases of fish into the sea until harvesting,

$$N_{t+1} = (1-m_t)(1-\alpha_t)N_t$$

By inserting Equation (3.3) into Equation (3.5), and assuming the amount harvested at each harvesting event to be identical, we derive α_t. Setting two subsequent extractions equal to each other yields,

$$K_t = K_{t+1}$$

$$w_t N_t \alpha_t = w_{t+1} \alpha_{t+1} (1-m_t)(1-\alpha_t) N_t$$

$$\left[1 + \alpha_{t+1}\frac{w_{t+1}}{w_t}(1-m_t)\right]\alpha_t = \frac{w_{t+1}}{w_t}(1-m_t)\alpha_{t+1}$$

$$\alpha_t = \frac{\frac{w_{t+1}}{w_t}(1 - m_t)}{\left[1 + \alpha_{t+1}\frac{w_{t+1}}{w_t}(1 - m_t)\right]}\alpha_{t+1} \tag{3.6}$$

We know that the final harvest event is equal to 100% of the total standing biomass and therefore $\alpha_{T_n} = 1$. From this point we iterate backwards from the final harvest event to find the value of α_t in the previous harvesting months. We assume that from the first harvest event takes place, the next harvest event takes place in the subsequent month, and so on.

The final harvest event is given by,

$$T_n = T_1 + (n - 1) \tag{3.7}$$
$$0 \leq t \leq T_n$$

The final harvest time denoted by T_n is the first harvest time plus the number of harvest events minus 1 since the first harvest event has already been accounted for.

Chapter 4: Data and Estimated Values

The following chapter explains the data used to generate results for different harvest scenarios. The different parameters used are summarized in Table 1.

4.1 Parameter Values

Initial Smolt Release	$R = 500\,000$
Initial Smolt Weight	$w(0) = 60\ g$
Feed cost	$C_f = 10.85\ NOK/kg$
Harvesting Cost	$C_h = 2.67\ NOK/kg$
Economic Feed Conversion Ratio	$\varphi = 1.21$
Discount Rate	$r = 9\%$

Table 1: Parameter values used in the analysis

4.1.1 Initial Smolt Release and Smolt Weight

The key production input is smolt. We assume that there are no smolt purchase limitations. In reality, the smolt production is restricted by the government, so the availability of smolt could potentially be limited. But since we mostly consider two generations of smolt, we believe that it is a fair assumption that smolt production capacities do not limit the subsequent production. According to the Directorate of Fisheries, in 2012, approximately 3.2 million smolts were sold to an average salmon farming company in Norway. An average company also has 6.7 concessions, which implies that the smolt release per concession were to be about 0.5 million smolts. In the analysis we will use numbers based on an average Norwegian salmon farming company, therefore we will use a smolt quantity of 500 000 smolts as our initial release.

Smolts can be released into sea pens from the weight of 40g, but the normal smolt release weight is about 60-70g. In our analysis we therefore choose an initial smolt weight of 60g.

Since smolt-stocking strategy is considered predefined by the fish farmer, smolt costs can be considered as fixed costs and therefore irrelevant cost elements for solving the optimal harvesting problem (Forsberg, 1999). Therefore, we do not account for smolt costs in the model.

4.1.2 Feed and Harvest Costs

We only consider the feed and harvest costs since they highly depend on the standing biomass, and will consequently affect the harvest decision. Additionally, according to the Directorate of Fisheries, the feed and harvest cost alone represent about 60% of the total production cost, supporting that these costs are important. The other production costs are assumed to be fixed and will therefore not influence the harvest decision.

Feed cost of 10.85 NOK/kg and harvest cost of 2.67 NOK/kg are based on cost statistics from 2012 reported by the Directorate of Fisheries. Feed cost is the main component of the production costs in salmon farming, and constitute around 50% of the total costs. The feed cost is dependent upon many raw materials, where the most important raw materials are fish oil and fishmeal. As marine raw materials are limited, the feed price may fluctuate along with fluctuating raw material prices. The harvest cost will potentially change with the harvest strategy; few harvest events could create need for additional labor force in relevant harvest periods, while many harvest events could give additional costs due to machines operating continuously and well boats travelling back and forth to the sea pens more frequently. However, throughout the analysis we assume that the feed and harvest costs remain constant.

4.1.3 Economic Feed Conversion Ratio

The feed conversion ratio tells us how many kg of feed we must give the fish for it to increase its bodyweight by one kg. The fish do not manage to eat all the feed that is thrown into the sea pen; hence some of the feed input is lost to the environment. The economic feed conversion ratio (FCR) includes this aspect and is the appropriate measure when feed costs are calculated. According to the Directorate of Fisheries, an FCR of 1.21 is normal for Norwegian salmon farmers. Moreover we assume the FCR to be constant since we do not include seasonal variations in the model. If seasonal variations were to be included, the FCR would probably vary since the fish would respond differently to the feed over the year.

4.1.4 Discount rate

Farming salmon is a risky activity. The price volatility implies uncertain cash flows which must be discounted at an appropriate risk adjusted rate. It is natural to assume that the salmon farming companies only activity is to produce salmon, so the company risk is approximately the same as the project or activity risk. The weighted average cost of capital is thus very well-suited for discounting the cash flows.

The industry specific WACC is 8-10%.[6] The production scale of the company will have an impact on their appropriate WACC. Companies such as Marine Harvest with large scale production could use a WACC of about 8%, while 9% is appropriate for medium sized companies such as Lerøy Seafood and Cermaq. For the smallest companies using a WACC of 10% is suitable. Intuitively, a small company with few cohorts is more exposed to price and cost variations than a large-scale production company with multiple

[6] The industry specific WACC was found in correspondence with analysts from ABG Sundal Collier and Lerøy Seafood.

cohorts and possibly production abroad. As well, vertically integrated companies are to some degree hedged since they have income from different activities, and should therefore not depreciate their cash flows with the same risk level as companies only pursuing farming activities.

We choose to use a discount rate of 9% which is appropriate for an average Norwegian salmon farming company. Since we have monthly time increments in the model, we convert the yearly WACC into a monthly discount rate. This is found by using the following formula,

$$r_m = (1 + r_y)^{\frac{1}{12}} - 1$$

With a yearly discount rate of 9%, we calculate a monthly discount rate of $r_m = 0.72\%$.

4.1.5 Weight Curve

We apply a weight curve estimated by ordinary least squares method based on growth observations for salmon (Asche & Bjørndal, 2011). The original weight curve is given by,

$$w(t) = 5{,}72t^2 - 2{,}08t^3 \tag{4.1}$$

The weight is a function of time t, which is years after smolt release. Since we want to analyze the production on a monthly basis, we convert the original function, Equation (4.1) to depend on months and not years. Equation (4.1) does not consider the initial smolt weight, so we adjust for that by adding 60g at the release date. The adjusted weight curve is given by,

$$w(t) = 0{,}039772t^2 - 0{,}001204t^3 + 0{,}06 \tag{4.2}$$

There are no restrictions to when the smolt must be released into the sea to fulfill this function. The maximum weight is obtained when the fish no longer grows. This happens when the derivative of the weight function equals zero.

$$w'(t) = 0 \rightarrow t = 22\ month$$

The weight curve implies that the salmon weigh 3-6 kg between the 12th and the 18th production month, which is regarded to be the salmon size that the processing industry prefers. Even though each individual fish grows at a slightly different rate we make the assumption that all the fish are identical, in other words we assume homogeneity among the fish in one generation.

4.1.6 Mortality Rate

In 2011, the average mortality rate over one production cycle in Mid-Norway was about 16%, which is also a best practice measure (Rosten, et al., 2013). The mortality rate in

Norwegian salmon farms may change due to different locations, smolt quality and husbandry practices. By using the best practice measure, the mortality rate should be around 1% on a monthly average. The mortality rate used in our production analysis is shown in Table 2 and is inspired by the mortality rate used by Frank Asche and Trond Bjørndal (Asche & Bjørndal, 2011).

In practice the mortality is high in the beginning of the sea phase since some of the smolts have not yet completed the smoltification process before release, and die when they absorb salt water. However, we assume that the entire cohort of smolts have all completed the smoltification process before release in sea water. Therefore we assume a low mortality rate of 0.5% during the first 10 months. Since we do not consider harvesting before 12 months have passed, the mortality rate is less relevant until harvesting is an option.

After 10 months have passed, the mortality is expected to increase since the space in the pen declines, continuously challenging the environment. The fish would most likely never stay in the net pen longer than 22 months, so the mortality from this point on is considered to be as high as 10%. Having in mind the best practice mortality rate of about 16% over the total production cycle results in the mortality for the remaining months shown below:

t	≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23
m_t (%)	0,5	1	1	2	2	3	4	5	6	7	8	9	10	10

Table 2: Monthly mortality rate in sea pens given in percentage terms

4.1.7 Price of Salmon

To be able to analyze the value of the biomass in the future, we need to make a price forecast. Since the model is analyzed with monthly time increments we apply monthly prices. We want to analyze the model for two different prices; a changing monthly price and a constant monthly price.

Estimating a Future Salmon price

The consumption of salmon has been highly seasonal in the past. However, in recent years salmon has become an everyday-product. Nevertheless, after studying Figure 5 in chapter 2, we recognize a weak pattern of seasonality in the historical prices from 2011, 2012 and 2013. The seasonal trend is that prices increase quite slowly during the first months of the year, followed by a decrease in April/May which last until September/October. In the last months of the year, prices increase again. Hence, we conclude that seasonality is still apparent in the market today although not as clear as before. Additionally, the forward price for 2015 shows a clear trend of the seasonality as detected in the historical prices with declining prices from April to September/October, and increasing prices in November and December. This implies that the historical average change in prices could be a good indicator to how the market believes the price will develop in the future.

For these reasons, we look at historical prices from 1995 to 2013 which are collected from Index Mundi.[7] The monthly deviations in prices are shown in Table 3 for the period 1995-2013. We take the average of the historical monthly price changes to get an impression on how the prices fluctuate over the year. The historical period regarded is 19 years which make the data reliable. In the estimation, we also need a basis price for the initial month of the year. As a basis price we use 40 NOK/kg which corresponds to the average price level from 2013 and the long term salmon price forecasted by Nordea Markets.[8] The monthly price estimates are presented in Table 3.

Month	Average historical change from 1995 to 2013	Estimated price forecast
Jan	0,33 %	40,13
Feb	1,71 %	40,82
Mar	3,15 %	42,10
Apr	3,71 %	43,67
May	0,66 %	43,95
Jun	-2,64 %	42,79
Jul	-1,13 %	42,31
Aug	-1,51 %	41,67
Sep	-3,55 %	40,19
Oct	-2,32 %	39,26
Nov	-0,88 %	38,91
Dec	5,54 %	41,07

Table 3: Average historical change in prices from 1995 to 2013 collected from Index Mundi, and estimated forecasted salmon price

There are several arguments for why a basis price of 40 NOK/kg is a fair assumption to make. First of all, the capacity level since the last issuance of new licenses in 2009 still remains today. In 2013, the average monthly price was about 40 NOK/kg. In December 2013 the salmon price increased to a new level with 48 NOK/kg, and it stayed surprisingly high during January and February 2014. This is an indication that the 2012 demand boost is still apparent in the market. Also, the 45 new licenses granted in 2014 will only equal approximately 5% supply growth, which is too low to meet a 7% demand growth. This indicates that the long-term price of salmon will stay on a relatively high level in the years to come, similar to the price level seen in 2013.

Since the companies are no longer in the position to expand production without new licenses, the market for licenses has become extremely attractive. According to the Directorate of Fisheries, during the 2014 license issuance, a market value of 66 MNOK

[7] Index Mundi is a web site that contains detailed country statistics, charts, and maps compiled from multiple sources. The site contains average monthly prices for a large number of commodities.
[8] Nordea Equity Research: Seafood sector update April 1 2014.

was uncovered. This has made the exit barriers in the industry low, since a producer can simply sell existing licenses to another and possibly larger producer, Marine Harvest for instance. With low exit barriers, and high entry barriers because of limited issuances of new salmon licenses, we assume that the salmon farming industry should be able to generate decent returns over time.

The current smolt release is a good indicator of future salmon supply. According to data from the Directorate of Fisheries, smolt release has been fairly stable since 2010, indicating that the market will not see a supply boost of salmon in the coming years.

Feed prices may also be a good indicator of how the price of salmon will develop in the future. One of the major feed producers, EWOS, reported in their yearly 2013 report that the average feed price in Q4 was NOK 9,69 per kg, which is the highest average feed price ever reported. With high prices of raw materials such as feed, the salmon price is also expected to stay high for farmers to maintain their margins.

Constant price based on Forward Prices

In our analysis, accounting for the fact that the future salmon price is highly uncertain, we analyze the biomass value and the harvest decisions given a more stable price based on futures contracts. Fish Pool Forward Price Database with closing date of 24.03.2014 presents future prices of salmon that are relatively constant for the next years; approximately 36 NOK/kg throughout the year in 2016, and 34.8 NOK/kg constantly through 2017 and 2018. This indicates that analyzing a constant price similar to the Fish Pool prices is relevant.

Additionally, if the entire industry were to smoothen out the supply of salmon, the price would probably stabilize as well. In this case it would be unfortunate not to have considered a constant price in the context of finding a harvest strategy. We choose to analyze the biomass value given a constant price of 36 NOK/kg.

Chapter 5: Analysis and Results

In this chapter we have used the model to analyze three different harvest scenarios of the cohort of salmon. The difference between these scenarios is decided by the number of harvest events. The following applies for each cohort,

- Scenario I: Harvesting occurs only once
- Scenario II: Harvesting occurs over 3 sequential months
- Scenario III: Harvesting occurs over 6 sequential months

Our hypothesis is that it is not optimal for the farmer to harvest smooth compared to harvesting all the fish at the same time. To test this hypothesis, we need to simulate harvest strategies for a farming company. The company is assumed to be average sized and Norwegian, with smolt release twice a year. As demonstrated in the background, May and October are the most favorable months to release smolt cohorts into seawater. The different scenarios are analyzed for three smolt release cases:

1. Smolt released in May – May fish
2. Smolt released in October – October fish
3. Smolt release is independent of the release date

If harvesting is non-smooth, the company will harvest each cohort once, resulting in two harvest events during one year, called batch harvesting. If harvesting is to be smoothened out over the year, each of the two cohorts should be harvested 6 times each. This is why scenario III includes 6 harvest events and not 12. Scenario II however, with 3 harvest events, is included in the analysis as a dummy-scenario to make sure we are not mistaken in our assumption that harvesting the cohort only once is optimal. Hence, scenario II works as an insurance and is not of main interest.

Since our main objective is to find the difference between batch harvesting and smooth harvesting, combining results from the model in a production planning context is more valuable to us than doing an extended sensitivity analysis for changes in parameter values. Hence, we find it more relevant to investigate different distributions of harvest events rather than observing how the objective function changes with slightly different parameters.

The analysis is based on May and October release of smolt. Both cohorts are analyzed for the optimal time to initiate harvest and the corresponding profits generated by the given harvest profile. The two cohorts follow the same growth function and will be equal during the production cycle, but the production cycle will correspond to different months in the calendar year. Accordingly the estimated price will impact the cohorts differently. For instance the price for May fish in the 12^{th} production month will be 43.67 NOK/kg while for October fish the price in the same production month will be 40.19 NOK/kg. A complete table of the estimated price for different production months for two release times of fish is included in the Appendix. We also assume a constant price in the analysis, which yields the same results during the production time. This is due to the same weight function being used for both May and October fish release. Therefore the biomass development for each cohort has an identical profile. The biomass and the individual fish weight curve are plotted in Figure 12.

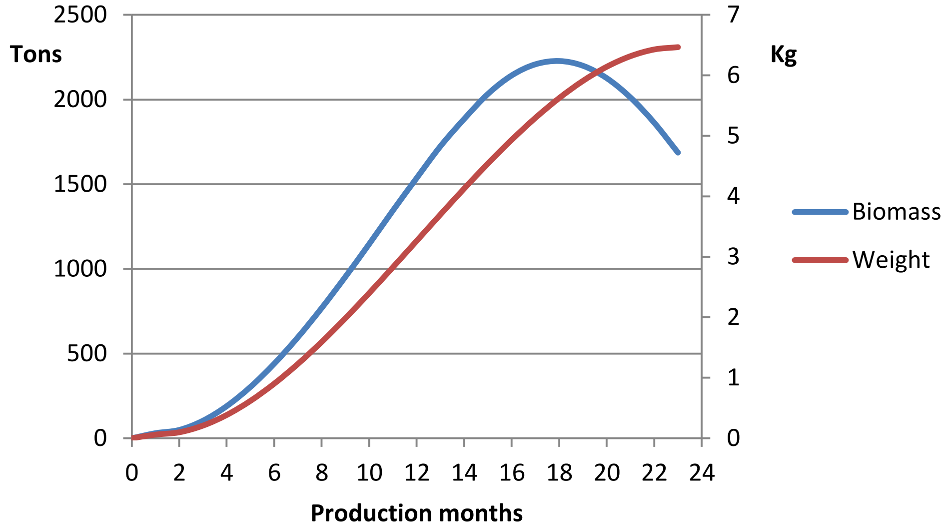

Figure 12: Biomass development in the sea pens and weight curve for each individual fish

As Figure 12 illustrates, the biomass reaches its maximum at the 18th production month, which is three months before the maximum of the individual fish weight. This is due to the mortality rate. Also, the biomass falls quickly after the maximum point. Therefore, our assumption regarding a relevant harvest period from the 12th production month until the 23rd seems to be a good assumption.

5.1 Scenario I: One Harvest Event

Figure 13 shows the value of the objective function, Equation 3.1, hereafter referred to as profits, for the different smolt release cases. The graph begins at the 12th production month and is only regarded until the 21st production month since the profits declines strictly after this. The figure shows how the profits changes with different harvest months.

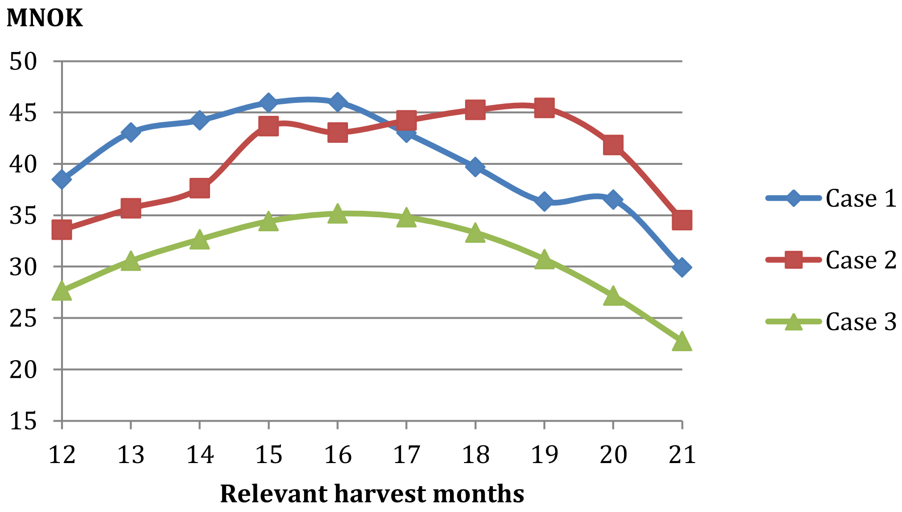

Figure 13: Profits for the different cases given Scenario I.

5.1.1 Case 1: May Fish

The profit from the cohort released in May depends on the estimated price. The optimal time to harvest is at $T_1 = 16$, which corresponds to August in the next year. Profit from this harvest is 46 MNOK, and the total feed cost during the production cycle is 28.5 MNOK. The total amount of salmon harvested during the one harvest event is 2142 tons.

Case 1 with release of May fish yields the highest profit for Scenario I. This is due to the fact that prices are high in the early production months, resulting in high profits before the biomass has reached its maximum point at the 18th production month. From Figure 13 it is clear that both the 15th and 16th production months yield highest profits, with 45.9 MNOK and 46.0 MNOK, respectively. The highest values are found in the harvest interval $T_1 = [13, 14, 15, 16]$. After the 16th production month the profits falls quickly.

Since salmon farming is risky beyond what is accounted for in the discount rate and mortality rate, it is likely that the farmer would harvest as early as possible given approximately equal profits. On the other hand, if we were to regard rising sea temperatures impact on the fish growth, the farmer has incentives to keep the fish in the sea for a longer period of time.

5.1.2 Case 2: October Fish

For the October smolt release, the cohorts yield a profit of 45.4 MNOK for the optimal harvest month $T_1 = 19$. April is the 19th production month for October release. Total feed cost is 33.2 MNOK and the total amount harvested is 2199 tons. The latter are larger than for May fish due to longer production time.

Fish released in October is exposed to lower prices in an early stage of the production, and higher prices later. This result in an optimal harvest time that occurs after the maximum value of the biomass is reached. Hence, the standing biomass is decreasing due to biological reasons when harvesting happens, while the biomass is still increasing at the optimal harvest time for May fish.

As Figure 13 show, the profits are approximately equal for the 18th and the 19th production month. The profits remain high for $T_1 = [15, 16, 17, 18, 19, 20]$, but then drops considerably from 41.8 MNOK to 34.5 MNOK from the 20th to the 21st production month. If seasonal variations were considered, the farmer would have incentives to harvest before and not after the winter. Keeping the fish in the net pens during winter is more risky due to rougher climate conditions. However, Figure 8 in Chapter 2 shows a salmon supply peak in March which indicates that our results for October fish are trustworthy.

5.1.3 Case 3: Independent of Smolt Release Date

When valuing the cohort based on a constant price of 36 NOK/kg, the release date does not matter as long as the weight function is equal for all release dates. The optimal time to harvest the cohort is at $T_1 = 16$, which generates a profit of 35.2 MNOK. Since the optimal harvest time is equal for Case 3 and Case 1, the feed cost and the total amount harvested is the same, respectively 28.5 MNOK and 2142 tons. The profits however are obviously smaller for Case 3 than for the other two scenarios, since the constant price is at 36 NOK/kg while the estimated price has an average of 40 NOK/kg.

Changes in the constant price will give the curve in Figure 13 a vertical shift upward for higher prices and downwards for lower prices. The constant price curve is the only curve with an exclusive single optimal point, since the profit curve is to a larger extent decided by the biomass curve shown in Figure 12.

5.2 Scenario II: Harvesting Occurs over 3 Events

Now we want to harvest the cohort over 3 sequential months. The relevant harvest interval is from the 12th production month until the 21st. After this, there is still room for two additional harvesting events after the 21st month. The profits given the different cases are illustrated in Figure 14. Since the harvest now happens over 3 months, the curves are smoother than in Scenario I. This means that several harvest events makes the profits less affected by the monthly price change.

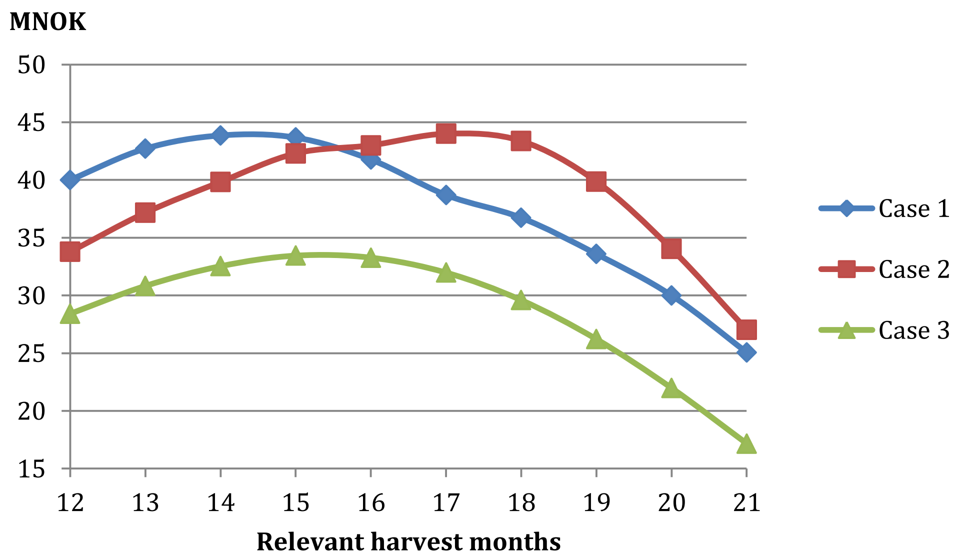

Figure 14: Profits for the different cases given Scenario II

5.2.1 Case 1: May Fish

The optimal harvest strategy would be to commence harvesting at the 14th production month, which corresponds to the month of June for fish released in May. In June, 35.6% of the standing biomass should be harvested, 51.3% in July and finally the rest of the standing biomass should be harvested in August. This strategy gives a fixed supply of 672 tons salmon at each harvest event, which gives 2016 tons in total. The profit generated is 43.9 MNOK, and the total feed cost during the production time is 27.8 MNOK. A summary of the optimal harvest profile is specified in Table 4 below.

Month	t	w_t	B_t (tons)	α_t	Harvest (tons)
Jun	14	4.13	1885	35.6%	672
Jul	15	4.54	1309	51.3%	672
Aug	16	4.93	672	100%	672

Table 4: Optimal harvest profile of May fish with three harvest events

The profit for the 15th production month is 43.7MNOK, which is very close to the maximum profit for Scenario II. However, with three harvest events, it could be favorable to start the harvest earlier to capture some of the high prices during spring. Harvesting May fish over 3 events result in nearly 6% less total harvested amount compared to Scenario I. The profit also declines with 5% by harvesting 3 times rather than once.

5.2.2 Case 2: October Fish

The optimal harvest strategy for fish released in October is to commence harvesting in the 17th production month, accordingly February. Profit generated from harvesting 737 tons in each of the 3 harvest events is 44 MNOK, and this is the highest possible profit obtained in Scenario II. Since production time is longer, the total feed cost is 32.8 MNOK and the total amount of harvested biomass is 2211 tons. A summary of the optimal harvest profile for Case 2 is specified in Table 5 below.

Month	t	w_t	B_t (tons)	α_t	Harvest (tons)
Feb	17	5.30	2208	33.4%	737
Mar	18	5.62	1484	49.7%	737
Apr	19	5.91	737	100%	737

Table 5: Optimal harvest strategy for Case 2 given Scenario II

Illustrated by Figure 14, harvest of October fish begins later in the production process than for May fish, resulting in almost 9% more salmon supply. The total amount harvested is in fact also larger for October fish given 3 harvest events and not only one. This however is not the case for the profits, which are higher in Scenario I.

In this case, the individual fish is allowed to grow to a relatively large size, which could provide additional value. Price premiums for larger sizes of fish in the market are not unusual.

5.2.3 Case 3: Independent of Release Date

The optimal time to begin harvesting a cohort that is independent of release time is in the 15th production month. The obtained profit from harvesting a fixed amount of 708 tons during 3 months is 33.4 MNOK. The total amount harvested is 2124 tons which is very similar to the amount harvested in Scenario I for Case 3, and the feed cost is 29.7 MNOK. The optimal harvest strategy is summarized in Table 6.

t	w_t	B_t (tons)	α_t	Harvest (tons)
15	4.54	2033	34.8 %	708
16	4.93	1396	50.8 %	708
17	5.30	708	100 %	708

Table 6: Optimal harvest strategy for Case 3 given Scenario II

5.3 Scenario III: Harvesting Occurs over 6 Events

Harvesting in Scenario III will occur over 6 months, which makes the 18th production month the last one to commence harvesting. The first relevant month is still the 12th production month. The changes in profits are smoother than in the latter scenarios, demonstrating a smaller influence from the volatile salmon price. The profits for the different cases in Scenario III are illustrated in Figure 15.

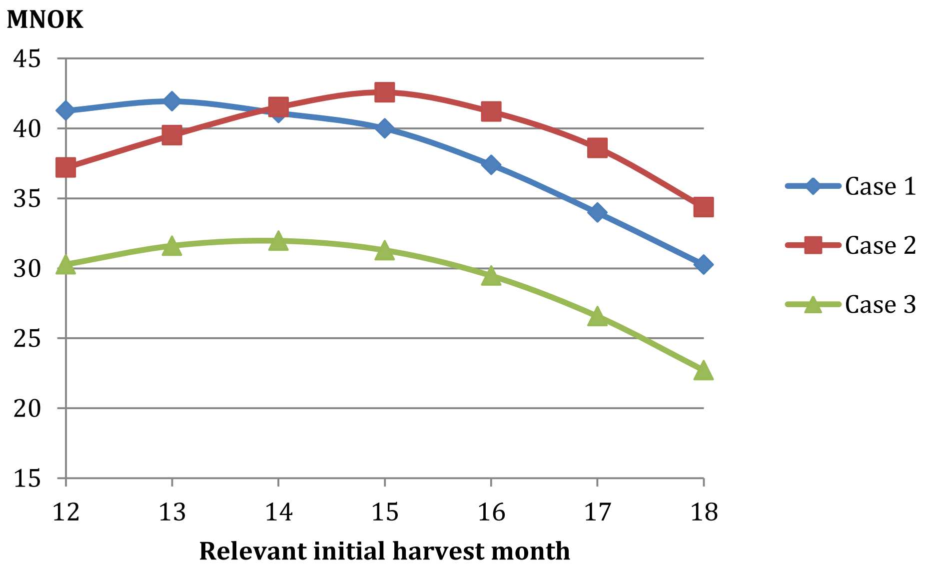

Figure 15: Profits for the different cases given Scenario III

5.3.1 Case 1: May Fish

When fish released in May is to be harvested over 6 months, it is optimal to initiate harvesting in the 13th production month. Harvesting 337 tons of salmon in each month from May to October yields a total profit of 41.9 MNOK. The total amount harvested is 2022 tons, which is almost the same as the total amount in Scenario II for May fish. Total feed cost is 28.6 MNOK. The optimal harvest strategy is summarized in Table 7.

Month	t	w_t	B_t (tons)	α_t	Harvest (tons)
May	13	3,70	1724	19,5 %	337
Jun	14	4,13	1517	22,2 %	337
Jul	15	4,54	1273	26,4 %	337
Aug	16	4,93	987	34,1 %	337
Sep	17	5,30	670	50,2 %	337
Oct	18	5,62	337	100 %	337

Table 7: Optimal harvest strategy for Case 1 given Scenario III

Since harvesting starts already in the 13th production month, the individual fish size is below 4 kg, which could be too small for the buyers' preferences. A fish below 4 kg is quite small and would normally be sold at a price discount, but since it fits with the industrial processing size requirements, we assume that the small fish is sold at the same price as the larger fish.

The profit obtained from 6 harvest events is almost 9% less than in Scenario I. Hence our hypothesis that batch harvesting is favorable compared to smooth harvest is confirmed for Case 1, May release.

5.3.2 Case 2: October Fish

If the cohort released in October is harvested over 6 sequential months, the maximum obtainable profit is 42.6 MNOK given initialization of the harvesting in the 15th production month. Since the estimated price is high during the winter month, the value of the biomass still remains high at a later time during the production resulting in optimal harvesting later than for May fish. The monthly fixed amount harvested is 359 tons, which result in a total amount of salmon supply of 2154 tons, which is larger than for Scenario I but smaller than for Scenario III. Total feed cost is 32.0 MNOK. The optimal harvest strategy for Case 2 is summarized in Table 8.

Month	t	w_t	B_t (tons)	α_t	Harvest (tons)
Dec	15	4.54	2033	17.7 %	359
Jan	16	4.93	1764	20.4 %	359
Feb	17	5.30	1448	24.8 %	359
Mar	18	5.62	1099	32.7 %	359
Apr	19	5.91	730	49.2 %	359
May	20	6.14	359	100 %	359

Table 8: Optimal harvest strategy for Case 2 given Scenario III

The profit from Scenario I is 6% higher than for Scenario III given October release. Scenario II yields a profit with a value between the profits from Scenario I and III. Our hypothesis regarding batch harvesting is thus also confirmed for Case 2.

5.3.3 Case 3: Independent of Release Date

For the cohort independent of release date it is optimal to commence harvest in the 14th production month. The corresponding profit is 32 MNOK which is obtained from extracting 351 tons of salmon in each of the 6 harvest months. The feed cost is 30.5 MNOK and the total amount of harvested biomass is 2106 tons. The optimal harvest strategy is specified in Table 9 below.

t	w_t	B_t (tons)	α_t	Harvest (tons)
14	4.13	1885	17.7 %	351
15	4.54	1654	20.4 %	351
16	4.93	1373	24.8 %	351
17	5.30	1053	32.7 %	351
18	5.62	707	49.2 %	351
19	5.91	351	100 %	351

Table 9: Optimal harvest profile of one cohort for a constant price of salmon

The change in profits from harvesting the cohort 6 times instead of once is over 9%. Our hypothesis regarding the optimality of batch harvesting is yet again confirmed.

5.4 Comparison of Scenarios

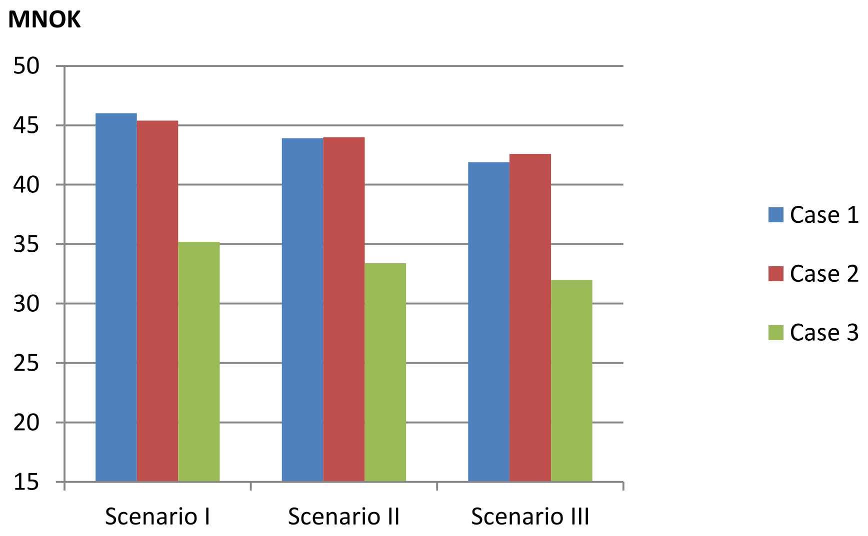

Figure 16: Comparison of the profits generated for the three cases given three harvesting scenarios

The profits generated by the three harvesting scenarios are shown in Figure 16. As mentioned earlier, all the cases have obtained highest profits in Scenario I, and lowest profits in Scenario III, which is what we expected. Hence, the most favorable strategy in a solely economic context, given our estimated and assumed prices, is to harvest the entire cohort once. This applies independent of the release time of smolts.

Case 1 and 3 gives approximately 9% fall in profits from one to 6 harvest events, while Case 2 only has a decline of 6%. An important observation is that it is relatively more costly for Case 3, which is based on a constant price, to harvest smooth compared to non-smooth. Hence if the entire industry were to produce smoother, the price would even out, and the incentives to batch harvest would again increase.

Harvesting only once makes the profit very sensible to the given price in the particular harvest month. Harvesting multiple times implies spreading out the revenues over different prices, and the total profit will become less sensible to price volatility. Harvesting multiple times could therefore make business more stable, but on the other hand it could take away the possibility to take fully advantage of very high prices over a short period of time. Another advantage with multiple harvest events is that there would not be as high density of fish in the net pen which could lead to a decline in mortality rate. This would increase profits in all cases. In general, increased discount rate, feed costs and mortality rate give the farmer incentives to harvest earlier. High prices occurring late in the production time, as well as a decrease in the parameters mentioned above, will give a rise in profits.

5.5 Harvest Planning

Results from the model applied on one cohort illustrate that no matter when the cohort is released, it is more profitable to harvest once rather than multiple times. We now want to extend the previous analysis of one cohort to a complete harvest plan over one calendar year for a salmon farming company. Harvest planning will provide us the opportunity to map the economic implications of a smooth harvest compared to batch harvesting throughout one calendar year.

By making use of the results and the analysis previously shown in this chapter, we will illustrate how a smoother harvest could be implemented for a farming company, and accordingly the potential losses in profits. We assume that the company releases one cohort in May and one cohort in October each year. The harvest planning is done with respect to the data and assumptions given in Chapter 4. Further, we assume that the company has produced salmon for some years so the production is now steady, meaning that a normal year contains both release of smolts and harvesting. Since the price is highly uncertain, we analyze the harvest planning with respect to both the estimated and the constant price.

5.5.1 Harvest Planning for Three Scenarios based on an Estimated Price

Figure 17 illustrate how a steady-state production year can be planned optimally for the different harvesting scenarios. The left column shows the smolt release taking place in May and October. To the right we find columns illustrating the harvested amount in the indicated months based on three different harvest scenarios.

		Harvest amounts (tons)		
Smolt input	**Calendar year**	Scenario I	Scenario II	Scenario III
	Jan			359
	Feb		737	359
	Mar		737	359
	Apr	2199	737	359
May release	**May**			359
	Jun		672	337
	Jul		672	337
	Aug	2142	672	337
	Sep			337
Oct release	**Oct**			337
	Nov			337
	Dec			359
	Total harvest (tons)	4341	4227	4176
	Profit (MNOK)	**91.4**	**87.9**	**83.7**

Figure 17: Harvest planning overview for three scenarios based on the estimated price

Scenario I results in batch harvesting during the year, and therefore has only two harvest events, one for each cohort. This is the harvest strategy that generates the highest yearly profit, 91.4 MNOK, and the largest total amount harvested, 4341 tons.

Scenario II is again included to assure us that we are correct by assuming highest yearly profits from batch harvesting and lowest profits from smooth harvesting. By increasing the number of harvest event from 1 to 3 for each cohort, the profit declines with 3.8%. If the company were to apply a harvest strategy based on Scenario II, there would be 5 sequential months without any salmon supply at all.

A smooth harvest is obtained by basing the harvest planning on Scenario III. Since we want approximately the same amount of salmon harvested in each month, we need to move the harvest initialization of May fish one month forward. This is favorable compared to moving the harvest of October fish. The last column in Figure 17 gives the optimal production plan for smooth harvest of salmon given a realization of the estimated price. We still regard the harvesting to be "smooth" even though the fixed amount harvested each month is slightly different for May and October fish. The smolts released in May are harvested in the summer months, and the smolts released in October are harvested in the winter months. By increasing the number of harvest events from 3 to 6, the profit falls with additionally 4.8%. In total, a yearly smooth supply profile gives on average 348 tons of salmon each month, and a yearly profit of 83.7

MNOK. This is only 91.6% of the possible profits gained by batch harvesting. Hence, 8.4% of the profit is lost due to multiple harvest dates.

Biomass development over one calendar year given batch harvesting

The yearly biomass for batch harvesting given that the estimated price is realized is illustrated in Figure 18.

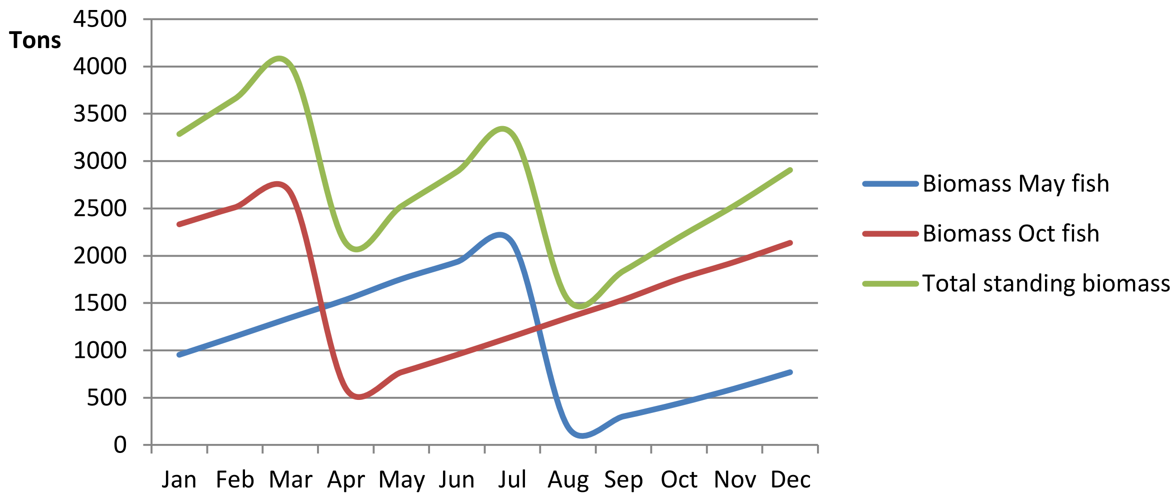

Figure 18: Biomass development for a non-smooth harvest profile during one calendar year

When harvesting twice a year, the total standing biomass is highly cyclical over the year. Each cohort is allowed to grow out completely before the entire cohort is harvested at the same time. This results in extremely high biomass in the sea right before harvesting occurs and a very low biomass afterwards. Even though a batch harvest profile yields the largest return on the smolt investment, the capacity required for when the biomass peak is substantially higher than for a smoother harvest profile. Intuitively, the MAB restriction would have a great negatively impact on batch harvesting.

Biomass development over one calendar year given smooth harvesting

The yearly biomass for smooth harvesting given that the estimated price is realized is illustrated in Figure 19.

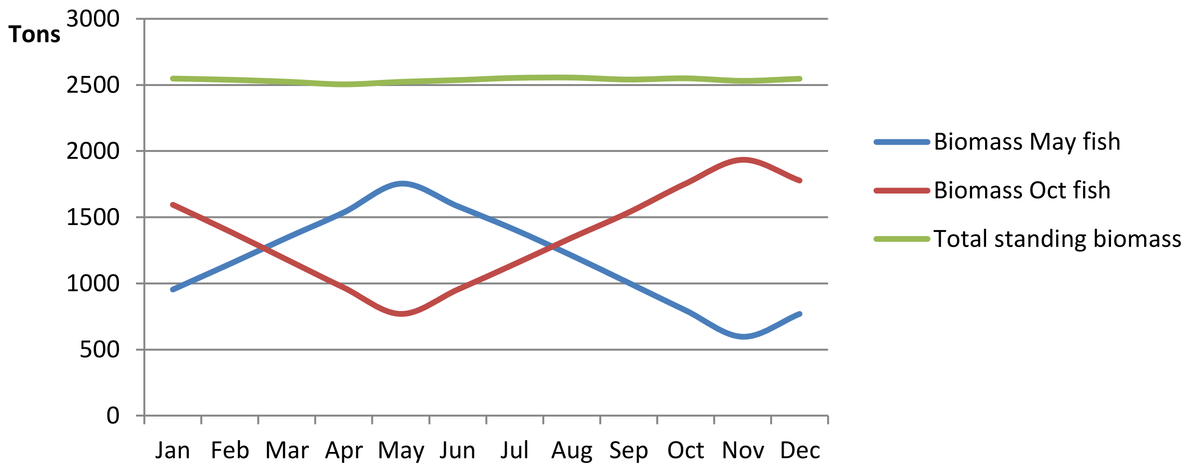

Figure 19: Biomass development for a smooth harvest profile over one calendar year

The standing biomass looks substantially different when the farming company harvests approximately the same amount of fish each month. Since harvesting is done continuously, the standing biomass will never be allowed to grow as large as it will for batch harvesting strategies. The overall harvest plan with cohorts released in May and October and harvesting salmon each month, results in a smoother, in fact nearly constant, total standing biomass over the calendar year. This is clearly shown in Figure 19. The fact that there is a six month time period between each release of smolt is an important contributing factor to the smooth curve.

Even though there is 8.4% loss in profit from switching from a batch harvesting strategy to a smoother strategy, the production capacity requirements are smaller in the smoother scenario. The standing biomass for batch harvesting requires 36.3% more production capacity than smooth harvesting, while the total amount harvested is only 3.8% larger for batch harvesting. Hence the amount of salmon produced per capacity unit is a lot higher in the smooth harvest scenario. If the farming company operates with a smooth harvest profile, they can simply adjust the amount of smolt released so that the nearly constant standing biomass always lies just below the MAB limit. Poor utilization of the MAB restriction could be very damaging to the farming companies, since capacity is limited in the salmon industry today.

5.5.2 Harvest Planning for Three Scenarios Based on a Constant Price

The harvesting planning for the farming company is illustrated in Figure 20, given that a constant price of 36NOK/kg is realized. The structure of the table is identical as Figure 19.

		Harvest amount (tons)		
Smolt input	**Calendar year**	Scenario I	Scenario II	Scenario III
	Jan	2142	708	351
	Feb		708	351
	Mar			351
	Apr			351
May release	**May**			351
	Jun			351
	Jul		708	351
	Aug	2142	708	351
	Sep		708	351
Oct release	**Oct**			351
	Nov			351
	Dec		708	351
	Total harvest (tons)	4284	4248	4212
	Profit (MNOK)	**70.4**	**66.8**	**64**

Figure 20: Harvest planning for two cohorts given a constant price

Again, harvesting based on Scenario I generate the highest profits, 70.4MNOK, and the largest total amount harvested, 4284 tons, by harvesting in January and August. Scenario II gives 708 tons of salmon supplied to the market in each of the 6 harvest months. There is a smaller gap between months of supply if the constant price is realized and not the estimated price. The yearly profit declines with over 5% when harvesting is initiated based on Scenario II and not on Scenario I. A smooth harvest based on Scenario III makes the profit fall with additional 4%. With a smooth harvest strategy, the company is able to supply the market with 351 tons of salmon each month during the entire year. The profit obtained with this strategy is 9.1% less than for batch harvesting. Even though there are large variations in profits for the three scenarios, the difference in the total amount harvested in the three scenarios is very small, less than 2%.

An interesting observation is that the decline in profit from batch to smooth harvesting is larger if the underlying price is constant and not changing.

Biomass development over one calendar year given batch harvesting

The yearly biomass for batch harvesting given that a constant price is realized is illustrated in Figure 21.

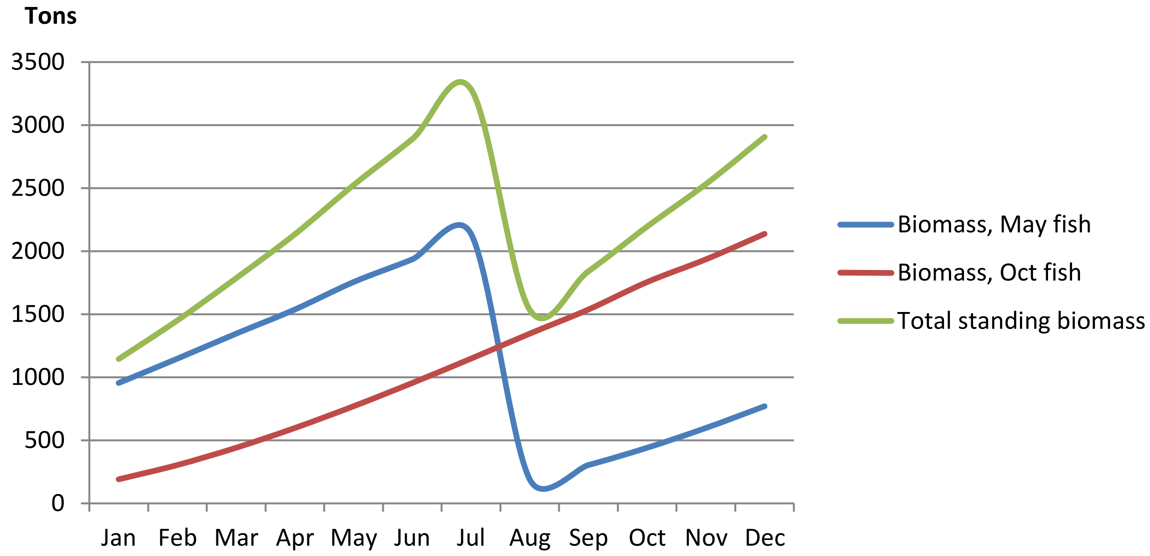

Figure 21: Biomass development for batch harvest given a constant price

When harvest is done only once, the biomass grows very large before being sharply reduced in the harvest months, accordingly in August and January. Since the harvest events are further apart in time when the constant price is realized compared to the estimated price, the standing biomass' maximum value is 18% smaller at the peak. Figure 18 shows the peak occurring in March for the estimated price, while the peak occurs in July given the constant price. The difference in the total amount harvested however, is only 1.3%. The fact that the constant price results in a low biomass during the winter could be favorable if we were to regard seasonal variations. Farming companies located in the north of Norway are exposed to lack of day light and cold sea water during the winter, which favors a harvesting strategy where the net pens are emptied before winter. Additionally, many companies experience increased risk of disease outbreaks and escapes during winter which also would favor this harvesting strategy.

Biomass development over one calendar year given smooth harvest

The yearly biomass for smooth harvest given that the constant price is realized, is illustrated in Figure 22.

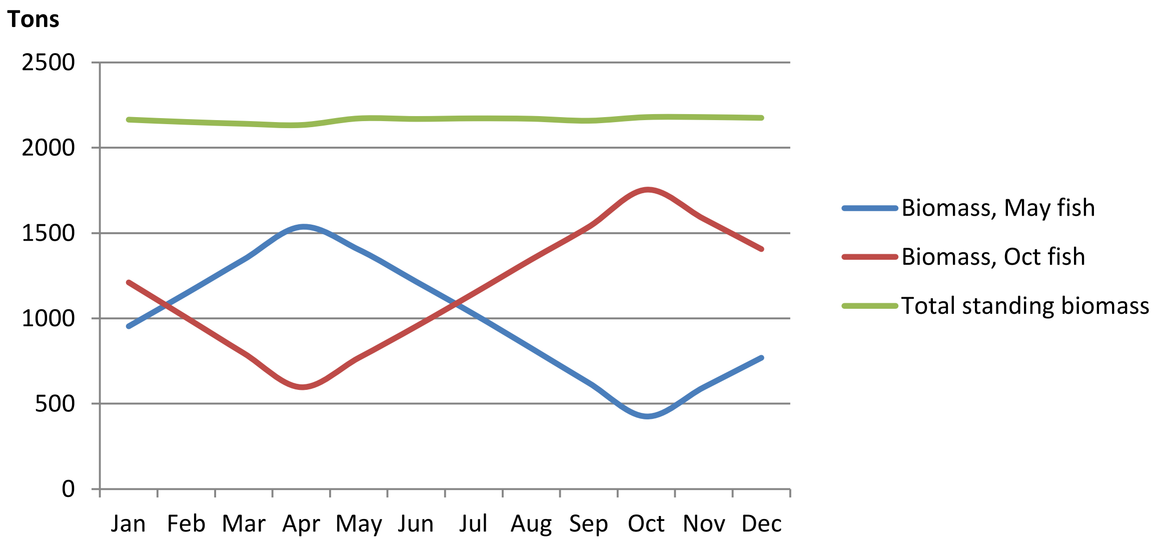

Figure 22: Biomass development for a smooth harvest profile given a constant price

The constant price results in a biomass development over the calendar year very similar to the one generated by the estimated price. The capacity required for the smooth harvesting strategy is 34% smaller than for the batch harvesting strategy, while the difference in the total quantity harvested is less than 2%. Since the resulting biomass over the year is approximately constant, the MAB restriction can be fully utilized and will not create large obstacles for the smooth harvesting strategy. However, it is uncovered that the loss of harvesting smooth compared to batch harvest is 9.1%.

The losses are only measured economically, and take no considerations for the relieved pressure on the environment and the possibilities for better utilization of the MAB restriction. Hence, we cannot neglect the fact that smooth harvest might be preferable in both price cases.

Chapter 6: Value Chain Analysis

According to the harvest planning in section 5.5, respectively 8.4% and 9.1% of the profits are lost by implementing a smoother harvest strategy given the estimated and the constant price. In the earlier chapters we have focused on the salmon farmer. In this chapter we want to investigate further how harvesting is conducted today and if the variations in salmon supply from the farmer affect the entire salmon farming value chain, from suppliers of equipment to processors and retailers. By interviewing different agents in the value chain, we have investigated how a smoother harvest may affect them. In the value chain analysis, we have focused on the challenges created by an uneven supply and volatile salmon prices. We have also focused on how the industry operates in practice. Our main focus is from the salmon farmer to agents further downstream in the value chain. We have been in contact with the following companies:

- Midt-Norsk Havbruk, a medium sized salmon farming company
- Lerøy Seafood, a large vertically integrated salmon farming company
- Morpol[9], a world leading company within processing of fish
- REMA 1000, a large Norwegian retail chain
- Lille Asia[10], a medium sized value-adding processor of fish

Furthermore, to get an academic and governmental perspective, we have been in contact with the following persons:

- Professor Frank Asche[11] at the University of Stavanger
- Department director of the Norwegian Ministry of Trade, Industry and Fisheries

In section 6.1, suppliers of equipment to the salmon industry are analyzed. In section 6.2 we analyze the salmon farmer. In section 6.3, processors are considered, and finally retailers are considered in section 6.4. In section 6.5 we analyze how vertical integration in the salmon industry may affect and contribute to a smoother harvest. In section 6.6, external factors from interest groups such as the government and the EU are considered.

---

[9] Morpol was recently acquired by Marine Harvest.

[10] Lille Asia is owned by Lerøy Seafood.

[11] Frank Asche is a Norwegian marine economist and his research focus is aquaculture and seafood markets. He is currently the president of the International Association of Aquaculture Economics and Management and associate editor of Marine Resource Economics.

6.1 Suppliers of Equipment and Fish Health Products

In the following section we will discuss and argue how smoother harvest may be favorable for suppliers of equipment and fish health products.

A challenge for suppliers in all industries is that their profitability depends upon the purchasing power of their customers. Suppliers of equipment and fish health products sell their products to the farmer, which is affected by large variations in profitability. When the salmon price is high, the farmer could be more willing to invest in new technology and equipment. However, when revenues are low, the farmer purchase only what is necessary from suppliers.

There are reasons to believe that farmers limit their investments in new equipment even when salmon prices are high. However, the two major challenges within the industry, lice and escapes, requires research and development, which increases cooperation between farmers and their suppliers. Effective vaccines, agent against parasites, solid net pens and so forth have been important success factors in the industry, indicating that a close relationship between suppliers of equipment and farmers has been essential for the impressive development of the industry in the last decade.

Smoother harvest could be more complex compared to batch harvesting. For instance, smooth harvest implies frequent interference with the fish, which is said to cause stress and reduce fish health and fish quality.[12] Salmon is a sensitive being, and stress could generate large problems such as reduced immune system of the fish and escapes from the sea pen. These challenges would create the need for veterinarian products, which is delivered by companies such as ScanVacc[13].

By harvesting and supplying smoother, the farmer is left with more predictable cash flows, which could increase their willingness to purchase products and services from their suppliers more frequently. As well, it can be argued that a smoother harvest has a lower impact on the environment compared to batch harvesting, which creates possibilities of differentiating salmon, and promote it as a "greener" and more sustainable product, based on production method. By promoting a "greener" alternative in the market, there are possibilities for price premiums, which illustrate how the farmer can regain the value spent on new equipment and other fish health products, creating additional value to several parts of the value chain.

Final evaluation of additional value to be gained through smoother harvest for equipment suppliers: Low.

---

[12] According to the Norwegian Institute of Food, Fisheries and Aquaculture Research (NOFIMA) stressful handling of salmon before slaughter result in faster reduction of fresh taste and smell, faster bacterial growth, and hence shorter shelf life.

[13] ScanVacc AS develops, import and market pharmaceuticals for the fish-farming industry.

6.2 Salmon Farmers

In the following section we will investigate the relationship between salmon farmers and smooth harvest strategies. We assume that the salmon farming stage include activities from smolt release to harvest and slaughtering. At the slaughtering facilities, the salmon is euthanized, gutted and packed in cooling boxes. After slaughtering, the fish is shipped abroad or delivered to Norwegian processors.

The results from our model are based on several assumptions, which make smooth harvest feasible in theory. However, in reality, smoother harvest may be more difficult to implement. We have therefore been in contact with salmon farming companies to investigate harvesting practices in the industry today and if a smoother harvest profile is possible to implement in practice. Additionally, we have tried to identify the farming companies' opinions regarding smoother harvest and other industry challenges.

6.2.1 Current Harvest Practices

In the following, we will present harvest strategies that exist in the salmon industry today. Furthermore, we will discuss how these harvest strategies lead to a non-smooth harvest pattern.

We begin by presenting the harvest strategy of Midt-Norsk Havbruk, which is a medium sized salmon farmer located in the middle of Norway. According to Tore Holand, the general manager of Midt-Norsk Havbruk, they harvest on a daily basis based on the growth in the biomass. They optimize their harvest profile with regard to the MAB limit and growth conditions in the sea. In total, their licenses give them a capacity limit of 13 000 tons. With growth conditions varying throughout the year with the different seasons, Midt-Norsk Havbruk only harvest the excessive growth in biomass every day, which obviously lead to the harvested quantity being different each day. For instance, daily biomass growth in February is about 40 tons, while in September it is 140 tons. On average, they harvest around 90 tons of biomass each day. This harvest strategy allows them to utilize 90% of their total capacity throughout the year, a strategy several large farming companies pursue.

The smaller farming companies on the other hand, harvest differently. As the harvest planning in Chapter 5 demonstrated, batch harvesting twice a year is the optimal strategy, and is hence the strategy used by many smaller farming companies. According to Professor Frank Asche, it is common for smaller companies to harvest 2-3 times per year, hence highly uneven harvesting. The larger companies on the other hand, deliver to large and demanding customers, usually through contracts, which require them to keep a stable and smoother harvest profile throughout the year to fulfill their obligations. According to Frank Asche, the standing biomass in the sea pens varies much more over the year than the amount harvested. Our results from Chapter 5 suggest the same, showing that batch harvesting result in a more variable standing biomass compared to the biomass in a scenario where harvesting is done more frequently. The fact that the larger companies try to harvest smoother combined with their dominant market shares, supports the statement made by Asche. Our results show that if a company only harvest a few times each year, the contribution from that company's supply to the total salmon supply in Norway will be highly uneven. However, our model is well suited for smaller companies and their contribution to the total Norwegian salmon supply is not very significant as the ten largest farming companies account for approximately 70%. The variations in total supply are perhaps slightly related to the smaller companies' batch harvest strategy and strongly related to the seasonal variations.

6.2.2 Smoother Harvest Profile

In the following we will discuss advantages and disadvantages of a smoother harvest. Furthermore, we will discuss whether a smoother harvest profile is likely to be implemented by the farming companies.

"We would harvest smoother if we were not bound by the current MAB restriction" - Tore Holand, general manager in Midt-Norsk Havbruk, commented about smoother harvest of salmon.

After being in contact with several farming companies, it becomes clear that the production volume restrictions, the MAB, and seasonal variations make it difficult for salmon farmers to harvest completely smooth. The growth in biomass in sea pens is analogue to interest or return of having money in the bank. When the interest is high, it is favorable to keep money in the bank, but when interests decline, the opportunity costs become too large. The same dynamic applies for the return on biomass in the sea. The biomass return is high during summer and fall, but low in the winter. This indicates that late fall is a favorable time to harvest the biomass. For instance, if Midt-Norsk Havbruk were to harvest an equal amount of fish each day throughout the year under the current MAB regime, they would on average harvest 22% less each day, and lose potential profits.

During winter and early spring, a smooth harvest would imply harvesting out more than the excessive biomass growth, resulting in a decrease in the total biomass instead of keeping the biomass on a steady level. This implies that with a smoother harvest under the current MAB regime, the capacity would not be fully utilized during the year. As well, with the current MAB regime and a smooth harvest, the farmers are forced to reduce the biomass before the best growth months in summer and fall to ensure that the biomass do not pass the MAB limit. Because of this, the opportunity to fully take advantage of the biology in the production is reduced.

In Chapter 5, our results from the harvest planning section shows a decline of 3.8% in the total amount harvested if harvest were to be completely smooth and not a few times each year. The losses in profits of about 9% also agree with the industry's view on the disadvantages with smooth harvest. In this matter it is important to remember that our analysis and results from Chapter 5 are based on two parallel cohorts, while Midt-Norsk Havbruk has a larger scale production. In addition, our model do not account for the MAB restriction, which forces harvesting in reality.

In our model, the estimated salmon price affects the harvest decisions due to its variations from month to month. For instance, October fish is always optimal to harvest a couple of months later than May fish. This indicates that the price triggers harvesting and hence works against a planned smooth harvest. However, in reality it seems like the price variations are not very decisive for when farmers choose to harvest. For instance, Midt-Norsk Havbruk does not let the price variations be an important factor when deciding harvest strategy. Holand confirms that if the price is particularly high at one point, and the biomass is larger than expected, they harvest out a little extra biomass during certain periods. This however, does not occur often. In reality, the production costs are more decisive than the price of salmon with regard to harvest. According to Professor Frank Asche, the production costs and the production risks varies over the year, with the most expensive harvest month being February. This is due to the seawater being colder and the daylight shorter in the winter, leading to fish not responding well to the feed. This leads to an increase in the feed conversion ratio (FCR), and hence an increase in feed costs. Additionally, the winter months are exposed to tougher climatic conditions, which increase the risk of damage on production equipment and higher risks of escapes. Also, in the winter months there are higher risk of disease outbreaks, which speaks in favor of harvesting large volumes of biomass before the winter begins. In our model, we do not account for variations in production costs as we do not regard seasonal variations; the possible effect could be that harvesting is triggered before the winter sets in.

An advantage with smoother harvest is that it may lead to more steady activity in the slaughter facilities, providing more stable work conditions and hence more attractive jobs for the employees. On the other hand, harvesting smooth could lead to well boats not being fully utilized to their capacity, as well as the slaughterhouses. Midt-Norsk Havbruk has solved this issue by owning 42% of a shared slaughterhouse owned by several other farmers. This allows all them to take advantage of the capacity in the slaughterhouse. But since there are several farmers sharing one slaughterhouse there is a capacity limit for each farmer, which requires the farmers to cooperate so that the slaughterhouse is not oversupplied nor undersupplied with fish, actually contributing to a smoother harvest of salmon.

There are many different opinions about how the demand for salmon looks like. Historically, there have been strong seasonal variations in the demand for salmon. Due to an increasing production of salmon and product innovations, salmon has become an everyday product, at least in Norway. For instance, in earlier years, salmon was either consumed boiled or smoked, and there was low demand of salmon during summer. This demand trend changed when it was discovered that grilled salmon is quite tasty.

However, Professor Frank Asche still believes that the salmon consumption is affected by seasonality and that this effect becomes more visible with increased degree of processing. On the other hand, the category manager for fish and seafood in REMA 1000, Trond Storrud, claims something different. He claims that REMA 1000 see no differences in demand for salmon throughout the year. A smooth harvest profile requires steady demand. In the current market for salmon, with limited capacity growth, demand is expected to remain higher than supply. In such an undersupplied market, the salmon farmer will manage to sell all fish independent of harvest strategy, indicating that demand is not necessarily an argument for harvesting smoother.

Finally, a smooth harvest profile would make it easier to sell salmon on contracts, in particularly forwards, with a specified amount delivered. Midt-Norsk Havbruk sells 98% of their salmon on the spot market, which, due to a highly volatile salmon price, is quite risky. In years like 2013, selling salmon on the spot market is favorable, but during times with low prices, farmers could benefit from having a larger amount of salmon sold through forwards.

6.2.3 High Salmon Prices – a Large Concern for the Salmon Industry

In the salmon farming industry today, it seems that capacity limitation is a more heated issue than a smoother harvest. We will analyze and discuss if higher salmon prices may be more damaging for the industry rather than an unsmooth harvest pattern.

"You have to do many things wrong to not make money today"[14] - Roger Pettersen, production manager in Marine Harvest region north, commented about producing salmon in the current market situation.

As explained earlier, the current capacity level is not high enough to cover growing demand, resulting in higher prices of salmon. Higher prices are obviously favorable for the profitability of the farming companies, but Trond Holand from Midt-Norsk Havbruk specifies two important side effects. First of all, higher prices lead to costs increasing. This dynamic is confirmed by the farming companies Lerøy, Midt-Norsk Havbruk and Professor Frank Asche. When margins are as high as they have been in 2013 it seems like farming companies are less aware of their cost levels, as reflected in the statement from the production manager of Marine Harvest region north, Roger Pettersen. In other words, expensive habits are added through good times in the salmon industry, just like tougher times inspire cost reduction. In the long run, this could be very damaging for the industry, especially in Norway where costs levels are high, when tougher times appear in the future.

The second important effect is that high prices trigger competition. Since 2013, there has been little competition between Norwegian producers because of an undersupplied

[14] http://www.aftenposten.no/okonomi/Dyr-laks-skaper-jubel-og-fortvilelse-7462211.html

market created by lack of available licenses. This has led to a trend where every farmer makes good money no matter how skilled he is. High prices indicate that the market wants more of the product and that consumers are willing to pay for it. If the sea based salmon farming as it appears today do not manage to meet demand, the prices would most likely remain high, making entry barriers lower. Other production methods such as land based salmon farming would then possess a threat. As well, new technologies could make it possible to farm salmon in countries that are not suited for salmon farming today. If the Norwegian producers in the meantime have been resting on the high prices of salmon, they might not handle new market situations. In other word, the importance of realignment could be forgotten in good times.

Final evaluation of additional value to be gained through smoother harvest for salmon farmers: Low.

6.3 Processors

In the following section we will present the current status in the salmon processing industry. Also, we will discuss how a smoother harvest of salmon may affect processors. In addition to this, we will investigate if processing of salmon really is profitable to pursue in Norway.

6.3.1 Processing Status Today

Over the years, some companies have tried to build processing activities during periods with low salmon prices, while later experience that with increasing salmon prices it is not possible to extract equal price increase for their processed products. This dynamic make the processing business a very risky. The variation in prices also results in a variable activity flow in the processing plants, which lead to poor utility of the plants, and makes the workplaces less attractive and hampers product innovation.

The break even cost to make processing profitable is about 44 NOK/kg for companies such as Morpol and Lerøy, and is probably higher for smaller companies due to higher costs. A break even cost of 44NOK/kg or higher would indeed make it difficult for processors to survive during times with high prices. The responding trend the last years has been both horizontal and vertical integrations through mergers and acquisitions. For instance Marine Harvest recently acquired Morpol, a Polish processing company with over 4000 employees.

A former employee in Morpol explains the imbalance of power in the value chain; *"The processors get sandwiched between large farmers and demanding retail chains"*. The fact that trade between farmer and processor takes place in the spot market, gives the farmer access to a lot of buyers. For instance, Midt-Norsk Havbruk has about 30 different customers, giving them room to choose according to the best deals. The farmer is not dependent on the processing activity to make good money, and hence could manage fine without the processor stage. Also, the large number of customers that most farmers have may lead to an impersonal client relationship where the clients', the processers, "well-being" is not in focus. Further downstream in the value chain, retailers buy the salmon products mainly on contract, for instance half year contracts, and this makes them very price cautious. The salmon spot price can change radically over short time, but the shelf price the consumer pays is not that easy to change overnight. Pressure from both sides has led to a high level of competition between the processors. This is good in terms of product innovation and cost awareness. However, with the farmers taking interest in processing as well, the smaller processing companies find it even more difficult to survive since they have no control over their raw material. The

2013 price level has led to several bankruptcies of processors both in Norway and in Europe.[15]

6.3.2 How Would a Smoother Harvest Impact the Processing Industry?

In this subsection we are questioning if and how a smoother harvest of salmon may affect the processing industry.

The price volatility and the high price level of salmon are without doubt a major issue for the processors. The essential question in this context is to ask if a smoother harvest would imply a more stable price. Even though we see a shift from supply-determined prices to demand-determined prices, supply will still have an important influence on the price. We believe that the prices would be less volatile over the year with a smoother harvest, but it will most likely not have a large impact on the high price level of today. However, if harvest becomes more predictable, incentives to trade on the futures market and not the spot market could increase. Today, there is little liquidity in the futures market, but with a larger share of trade happening through forwards, the spot price would be smoothened out as well. This would take away some of the risk on the input side, making processing activity easier.

Secondly, a smoother harvest would be beneficial for processors because it means more stable supply of raw materials to the processing facilities. With a more stable supply, it is easier for the processors to plan the production and maintain a stable work flow, enabling the processors to deliver stable flows of products to retail chains and other customers. This could facilitate the connection between the processors and the market, inspiring innovation and development within the product portfolio. The market wants more salmon, and the consumer wants it to be easily prepared.[16] Being aware of what consumers prefer is highly important for the development of new innovations, which again lays the foundation for more value creation in the processing stage. As the harvest is today, there is a lot of relatively inexpensive fish on the market during fall. After the processors have delivered products according to the agreements with the retailers, there might be room for developing new products, since the price is good. However, when the supply declines and the price increases, the processor must secure income and hence cannot afford to be "inventive". Therefore, a smoother salmon supply could make it easier to test products in the market and create further value.

6.3.3 Is it Profitable to Pursue Processing Activity in Norway?

While a smoother harvest of salmon is the main issue in this analysis, we are curious if it really is profitable to pursue processing activity in Norway. The advantage with

[15] http://www.aftenposten.no/okonomi/Dyr-laks-skaper-jubel-og-fortvilelse-7462211.html

[16] Statement made by Rasmus Larsen, former COO of Lille Asia.

processing in Norway is that the farming and processing of salmon can be localized near each other. Fresh salmon products that are sold in the Norwegian market are mainly processed in Norway. Since the industry tends to saturate the Norwegian market, the processors are required to follow the market development. For instance from 2010 to 2013, the Norwegian consumption of sushi increased by 95%.

Salmon is a global product and one of Norway's most important exports commodities. This implies global prices and favorably also global costs. Norway's disadvantage is that the cost level is high, but the output produced competes on an international level with low cost countries. According to SINTEF[17], the challenges concerning price has led to the majority of 3800 annual full time equivalent within processing in Norway to be occupied by the large farming companies. "*The independent processors that do not possess licenses to farm salmon disappear, while an increasing part of the processing is done by the large farming companies. I believe there is a real danger that the independent processors will disappear completely*" – Svein Reppe, managing director in The Norwegian Seafood Association (NSL). About 15-20% of the Norwegian produced salmon is processed in Norway and this share has maintained pretty stable since 2000. However, the amount of processing companies have more than halved over the last ten years due to mergers and acquisitions as well as bankruptcies. Moreover, the magazine Norsk Fiskerinæring claims in their May issue[18] that the processors have lost approximately 1.8 billion NOK over the last ten years by filleting salmon in Norway. Hence processing of salmon does not seem to be very profitable to pursue in Norway.

For Norway to be able to process salmon with both high employment and high profitability in times of high salmon spot prices, the consumer must be willing to pay more. A former employee in Morpol says that the Norwegian consumer can tolerate a higher price, but not a lot higher. Frank Asche as well points out that it can be profitable to process in Norway if the right products are developed. He does not view the fact that some consumers fall off as a problem since demand is so strong. The industry must create additional value for the consumers which need to be high enough to make up for cost disadvantages. The companies that manage this are usually approaching niche markets. These are few and produce in relatively small volumes, but can take a nice premium.

6.3.4 Innovations in the Industry: The Case of the Salmon Product Salma

In the following we will present an example of a successful innovation in the salmon industry, called Salma salmon. Salma is a salmon product found in many supermarkets in Norway. Salma is vacuum-packed within four hours of being taken from the sea, and distinguishes itself from other fresh salmon products by being of superior quality and delicate packed. Salma is a quality product, and it is gaining loyal supporters both in

[17] SINTEF is the largest independent research organization in Scandinavia.
[18] http://www.ilaks.no/har-tapt-18-milliarder-pa-videreforedling/#.U4of3SjGeqY

Norway and internationally. Salma illustrates how research in the value chain could result in a very successful product.

Salma is a rare example of an innovation process on a fresh fish product that has led to a strong brand with high recognition in the market. It can be argued that branding of salmon products is highly difficult because seafood is so-called commodities, with uncertainty regarding volume and price. It is difficult for a company to differentiate their product, and copying of another successful product is normal in the salmon industry. The "free-passenger" problem is hence a challenge when branding salmon and other fresh seafood. That is why producers of fresh seafood make limited investments in product differentiating and branding. Still, some companies have succeeded in building a strong brand based on fresh fish, for instance Salma.

Salma has managed to establish a strong position in the Norwegian market. Salma's success is a lesson in how a traditional raw ingredient producer has made processing profitable in high-cost Norway. The vital element has been focus on quality. The case of Salma illustrate that processing can be profitable in Norway. Through their market strategy and knowledge Salma discovered that the market do not necessarily prefer strongly processed products. Having access to high quality raw materials and knowing what the consumer wants, made it possible to produce a uniform high quality product. According to retail chains, uniform quality was the most important attribute to the innovation of Salma.

When the former owner of Salma, Tine, decided to invest in salmon products they had a need for a permanent supplier, both to ensure good quality and to ensure safe supply of raw materials. Earlier, they had problems with unstable supply of salmon when they ran Marian Seafood with Gilde. Tine chose Bremnes Seashore because of its good quality, and they engaged in a new shared ownership, called Salma Brands. Tine received smooth quality and supply, something they were not able to receive from the salmon spot market with many actors involved. With a smooth supply of salmon to the primary processor, Salma was able to be visible in the market at all times and maintain a strong brand which again generated a price premium and additional value to the entire value chain.

Final evaluation of additional value gained through smoother harvest for processors: High.

6.4 Retailers

In the following we will analyze the current situation for retailers in the salmon market, and then we will discuss how retailers may be affected by a smoother harvest of salmon.

6.4.1 Demanding Retailers

Food retail chains are in many respects the most demanding buyers in the salmon value chain, with strict requirements and demands. This has created difficulties further up in the value chain, especially for the processors. Requirements in terms of product price, volume, logistic costs, regularity and security in supply, product attributes, shelf life, production process, products range, documentation, and traceability, restricts both farming and processing activity. There are many reasons to why retailers are in position to make these demands. First of all, the fact that retailers are the largest buyers of salmon in Europe after hotels and restaurants, gives them huge market power. Secondly, technological and organizational improvements have occurred in several parts of the value chain making it easier to demand attributes such as traceability. Thirdly, higher level of competition between processors has made it easier for retailers to choose suppliers that can secure supply at reasonable prices. Finally, retailers are in direct contact with the consumer and hence know exactly what they want and can provide important information to the value chain.

With regard to a smoother harvest of salmon, it is interesting to investigate if retailers experience periods with lack of salmon supply. According to Trond Storrud, category manager of fish and seafood in REMA 1000, there are only a few periods where it can be difficult to get hold of salmon. This usually happens after holidays, mainly due to high demand and the fact that salmon farmers are also enjoying their vacations. But in general, REMA 1000 experience good availability of salmon throughout the year, indicating that variations in supply do not have any significant impact on Norwegian retailers. This again is a result of the industry trying to saturate the Norwegian market. How the multinational retail chain Carrefour however experiences the availability of salmon abroad is likely to be different.

According to Storrud, REMA 1000 is neither very influenced by large price variations. REMA 1000 usually purchase over 50% of its salmon product through contracts, and are therefore to a large degree hedged against price risk. They experience relatively stable consumer demand without any specific seasonal variations, and must therefore have price-decided contracts throughout the entire year. He claims that the competitive situation in the retail market is what decides the final consumer prices, and not the raw material price. "*The spot price of HOG salmon has never fully been reflected in the final consumer prices*"- Storrud's comment about demand destructive price levels of salmon. REMA 1000 has never driven the price of salmon products to a demand destructive level. The reason for this could be that there is more to lose by upsetting the consumer, rather than just taking the cost themselves. Today, retail chains rank among the largest companies in the world, and they seek to brand their chains with respect to other factors than price as the only measure of competitiveness. Hence it is important for large retailers such as REMA 1000 to maintain its customer base, and in that matter the retailers keep in mind that salmon only accounts for some out of hundreds or thousands of products. However, when final consumer prices increase, they see some declining but not dramatic changes in demand.

6.4.2 How can a Smoother Harvest of Salmon Benefit Retailers?

After obtaining an insight in REMA 1000 views on the market for salmon, it seems like large retailers, at least in Norway, are not very influenced by the variations in neither supply nor prices. However, with a trend towards consumers being more aware of product quality and traceability, a smoother harvest could benefit the retailers on some levels. A smoother harvest could entail more stability further up in the value chain, which could make it easier to cooperate between retailers, processors and producers.

Some retail chains also have their own quality labels that impose product and production standards on suppliers. With an increasing trend towards retail chains promoting salmon products as "own-label" brands, their own reputation is suddenly at stake if the products does not live up to its expectations. Thus a good relationship with suppliers becomes increasingly important. For example, the multinational retail chain Carrefour, sell salmon under own quality labels, which requires a close relationship to its suppliers. For Carrefour, a smoother harvest could make it easier to control quality and ensure stable deliveries of "own-label" products, making their store more attractive.

For retailers it can be difficult to trade with processors that are highly affected by both the harvest and the price of salmon. Imagine a retailer having a six months contract with a processor that is suddenly going bankrupt. Due to competition between processors, it should not be difficult to get a new contract with a different processor, but there are still risks connected to changing processors. Additionally, when the processors are facing tough times, there is reason to believe that they will cut cost no matter what. Doubt could be drawn to whether the desired processing requirements are fulfilled. With retail chains labeling the salmon products as their own, the risk of having a processor that does not deliver as expected could create a challenging situation.

As well, smoother harvest would provide processors with more stable deliveries of salmon, leading the way for more innovation and new products, which could boost demand and benefit retailers that have popular salmon products in their product portfolio.

All in all, a smoother harvest of salmon may benefit retailers, but it seems like a larger concern is the high salmon price. This brings up the demand destruction issue again. The question is if consumers will flee from salmon because of the high prices. To be able to continue to create value in all parts of the value chain, the consumer must be willing to pay the price. In some markets, in particularly in Russia and France, there are certainly signs that his has happened. According to Kolbjørn Giskeødegård, senior analyst in Nordea Markets, Russian and French consumers are the most sensitive to changes in prices. He says that the Russian market has switched from Atlantic salmon to less expensive alternatives, such as trout, because of the high price levels. If such consumer reactions take place in Norway as well, it will have large consequences for the entire value chain. "*The prices cannot increase much*" – former employee of Morpol commented on how far the prices can increase in the future before demand destruction sets in. The consumer is used to get hold of salmon at all times and at stable prices, and the high price level could compromise that. Both because the retailers cannot sell salmon products at negative numbers over a long amount of time, and since each time a stage in the value chain falls out, possible market shares are lost.

Final evaluation of additional value to be gained through smoother harvest for retailers: Medium to Low.

6.5 Vertical Integration in the Salmon Industry

The extent of vertical integration in the value chain for salmon was limited until the late 1990s. During the last decade, however, there have been several developments that have led to tighter vertical integration from salmon farming companies to the retailers. Most obvious is the rise of large horizontal and vertical integrated companies with direct ownership of production activities from hatcheries to fish processing and exporting. In the following we will discuss vertical integration in the industry in relation to a smoother harvest.

The emergence of very large retailers and supermarket chains has been accompanied by consolidation in the salmon farming sector, resulting in many companies seeking a higher degree of integration. Examples in aquaculture are Marine Harvest, Lerøy and Salmar. Vertically integrated companies often control both production and processing stages, and sometimes also feed manufacturing or other activities. The increasing amount of requirements from large retail chains has been a main driver for vertical and horizontal integration. The objective has been to increase the negotiation power towards the retailers with respect to price, product, and volume.

The price variations are also an important driving force, both for the farmer and the processor to become vertically integrated, as avoiding trade on the spot market would make both activities less risky, especially for the processor. An interesting aspect is if vertical integration may lead to a smoother harvest of salmon. Vertically integrated companies with both farming and processing activities are most likely better off with producing smoother since operating their own processing facilities optimally are dependent upon stable deliveries of salmon. Also, the salmon farmer could gain more information about the market by being vertically integrated, which could lead to farmers producing more according to demand which would benefit all the stages further downstream in the value chain.

With the current situation in the salmon industry, processors are “squeezed” between the farmer and the retailer. Both farmers and retail chains make good money, but the processors on the other hand struggles. The only processors that have been profitable in the last year are the ones that are either fully integrated or produce to niche markets. With large variations in salmon prices, there is almost impossible to process salmon in Norway without any coordination to farmers, especially when main processing competitors are located in low-cost countries or are fully integrated entities. It can be argued that until prices stabilize at a level where all the agents in the value chain can see returns, processors are basically forced to be vertically integrated with a salmon farmer.

Vertical integration could naturally be a good thing for retailers and buyers of salmon, as they operate economies of scale, and thus are able to provide retailers with salmon throughout the year. This is due to larger companies having many farming licenses, and by being vertically integrated they can plan their production so that they can deliver salmon to the market in smoother terms. Also, with retailers having stricter requirements to salmon products, and consumers seeking information about traceability, it could almost be a necessity for salmon producers and processors to be vertically integrated in order to live up to such requirements in the future.

Lerøy Seafood is an example of a vertically and horizontally integrated company with farming activities, value-added processing, sales and distribution. According to Jonas Langeteig in Lerøy, they produce relatively smooth over the year, but they would like to produce even smoother. The problem for them is the same as for Midt-Norsk Havbruk; they are bound by the current MAB limit. Since the vertically integrated companies normally have a large scale farming production, they have several cohorts going at the same time. This enables them to harvest smoother as discussed in section 6.2. But even large vertically integrated companies find it difficult to harvest smooth, mainly due to the combination of salmon farming being a biological production process and the MAB regime.

If the development towards large vertical integrated companies continues in the future, there are reasons to believe that these large “giants” would outperform smaller salmon farmers and processors on volume and cost level. For instance, with the merge of Marine Harvest and Morpol, the company is now the largest fish farmer and the largest processor in the salmon industry. If other large integrated companies want to grow to such a size, they would have to acquire the smaller players, eliminating the diversity in the industry. Also, in a scenario where “giants” such as Marine Harvest process more of their own produced fish, there would be less available fish on the spot market, leaving independent processors with higher salmon prices and less supply. Such a scenario would also encourage to vertically integration.

All in all, vertical integration in the salmon industry seems to have the side effect of being a smoothening mechanism for salmon supply, and with this being an increasing trend it is likely that the supply in the future will have a more smooth profile than today. We have mentioned earlier that it is the smaller companies that mainly produce very unsmooth, with only 2-3 harvest of fish each year. With smaller farmers becoming vertically and horizontally integrated, the noise in supply created from their contribution would be damped.

6.6 External Interest Groups Affecting the Salmon Value Chain

There are many external interest groups affecting the salmon farming value chain. Most visible are the government with regulations and licenses, international markets and their trade barriers and the media. In the following section we discuss how external interest groups may affect how the salmon industry operates and hence how such groups may have an impact on harvest profiles.

6.6.1 The Government – Regulations and Licenses

The Norwegian government has large impact on the salmon farming value chain. Salmon farming has been subject to substantial political focus and governmental regulations in many years. Since the industry is dependent upon natural resources which are considered public property, a certain degree of regulation in the industry seems fair. The development of the industry is dependent upon salmon farming being done in a sustainable way both environmentally and economically, which makes government involvement important. We have been in contact with Martin Bryde, director at the Ministry of Trade, Industry and Fisheries, to clarify goals and measures that the government envisages for the future.

A Market-Oriented Production

The government presented their Fresh Fish Strategy in the Declaration of Soria Moria in 2007. The strategy is based on the fact that the consumer is willing to pay a higher price for fresh fish rather than frozen fish. Pointing out the inconveniences implied by seasonal variations, the Fresh Fish Strategy had amongst its goals to "*contribute to continuity through increased and smoother supply of raw material during the entire year*".[19] This will be done through specific measures. Hence, it is clear that the government has interest in a smoother harvest, and could introduce measures in this matter that will directly affect the salmon industry.

With an objective to make harvest of salmon more market-oriented, the government desire results such as increased value creation and more stable workplaces in coastal areas. Bryde explains that even though *value creation* is an economical term, it is expanded in a political context to include the activity level as well. Hence, the government's objectives include elements of regional policy, and have an emphasis on the development of local communities. In this matter, according to Bryde, processing activity is highly relevant, since the delivery of advanced and processed products throughout the year is important to extract more value from the entire salmon farming value chain. As mentioned earlier, the Norwegian processing industry faces many challenges in the current market. Therefore there have been made several requests from processing companies to the government. *"Large parts of the processing industry, us included, have red figures in 2013. If the politicians do not act soon, I am afraid that we*

[19] Meld. St. 22 (2012-2013) Verdens fremste sjømatnasjon

will not exists in three years"[20] – Sigurd Rydland, general manager in the Norwegian processing company Taste of North, commented about the difficult situation that Norwegian processors are facing. He had to lay off 20 employees and stop all filleting and smoking of salmon due to the current situation in the salmon market. Since there is a political agreement that there should be processing activity in Norway, the government is trying to facilitate better conditions for the processing industry. Rolling MAB is an example of this.

The government's objective with a rolling MAB regime is to create a more market-oriented harvesting. Since demand is continuously rising and seasonal variations in consumption are going down, one can expect that it will become highly profitable to produce according to the market. And the market wants salmon throughout the year. Hence, one can expect that a rolling MAB regime would result in a smoother harvest, since salmon farmers would have the possibility to produce smoother and still take fully advantage of the MAB limit. A rolling MAB would be particular favorable for smaller salmon farmers, which today have trouble taking advantage of the capacity limit with their batch harvesting strategy. This was as well explained in the harvesting planning section in Chapter 5, where batch harvest result in a poor utilization of the MAB limit. According to Asche, smaller companies do not have large scale production during winter due to poor growth conditions. Therefore, with a rolling MAB, smaller companies could produce more when it is good growth conditions in the fall, and still have the same biomass in the winter as they have today. Combining this with our results, we have reason to believe that the rolling MAB would only facilitate batch harvesting which is shown to be more profitable in Chapter 5.

Many experts are skeptical to a rolling MAB and claims that it would work against its purpose. According to Professor Guttormsen at NMBU[21], a rolling MAB would result in farmers taking advantage of the good growth conditions for salmon in the third quarter of the year, and simply increase production in that period.[22] This would just lead to a growth in total production, and not a smoother harvest. A rolling MAB could also compromise the environment at the locality. The increased biomass pressure during certain periods could boost the risk of disease outbreaks and lice. The water quality could also be endangered, leading to consequences for the growth rate and the quality of the fish.

On the other hand, a rolling MAB could lead to a smoother harvest of salmon if the farming companies decided to do so. This could facilitate more employment in both production and processing activities, which is precisely what the government wishes, namely more stable and attractive workplaces in coastal areas where the salmon farms are located. At the FHL yearly conference held in Trondheim in April 2014, it became

---

[20] http://www.aftenposten.no/okonomi/Dyr-laks-skaper-jubel-og-fortvilelse-7462211.html#.U38mKyjGeqY

[21] Norwegian University of Life Sciences

[22] From his presentation at the Norwegian Seafood Council seminar April 11, 2013

clear that the industry in general wants to produce smoother, but that smoother harvest is not favorable under the current MAB regime. Lerøy claims that the primary concern for salmon farmers ought to be the year-round stability. Furthermore Lerøy suggest that the rolling MAB could be a possible measure to increase flexibility in harvest decisions. This as well corresponds to Midt-Norsk Havbruk when they claim that the MAB limit is as good as solely deciding their harvest strategy.

Marine Harvest however is concerned that a rolling MAB regime will have negative impact on environmental sustainability in the industry. They prefer a continuation of the current MAB system, with annual capacity increases of 3-5% for ten years, if deemed sustainable. Marine Harvests attitude towards the rolling MAB may have something to do with their large scale operation in Chile, a country with less seasonal variation than Norway. Roughly, the companies having farming activity on the other side of the Atlantic Sea are usually against the rolling MAB.

Another measure the government has introduced in order to facilitate the conditions for the processing industry were linked to the licenses granted in 2008. A given amount of these licenses were supposed to be granted "*the smaller players in the salmon farming industry*" and to the applicants that aimed at facilitating "*processing activity and increased value creation along the coastal districts in Norway*". At the FHL conference, a salmon farmer expressed his frustration against the imposed installation of a processing plant which is not profitable to operate. The fact that installing unprofitable processing plants was a requirement for being granted growth options, does not speak in favor of value creation from that operation. According to Asche, these licenses had a market value of 50 MNOK, but were granted at the price of 8 MNOK. So even though the processing plants operated with losses, the profit gained by those who were granted licenses was high. Nevertheless, the farming companies that were granted these licenses would probably not have started up with processing if it were not for the extra capacity gained. We asked Bryde what experiences the government had from this license round and the requirements made. The answer was that there were no follow-up or monitoring after the licenses were granted. Hence, if the 2008 licenses contributed to a smoother harvest is difficult to say.

Predictable Growth

Markets on both a national and an international level want Norwegian salmon and they want more of it. Hence, with the high price level of today, the farming companies want to increase production. Midt-Norsk Havbruk and Marine Harvest are amongst some that believe a 3-5% yearly capacity growth is sustainable and reasonable. The new governmental platform[23] lists among the goals within Fisheries and Agriculture; "*The government wants to facilitate predictable growth in the aquaculture industry*". Under the FHL conference, the Minister of Fisheries, Elisabeth Aspaker, said that "*We want growth in the aquaculture industry, but it must be made within sustainable limits*". With

[23] http://www.regjeringen.no/pages/38500565/plattform.pdf

sustainable limits it was referred to the issues regarding sea lice and escapes. When we talked to Martin Bryde, he confirmed that predictable growth is in fact a goal, but at the same time he claims that "*it is impossible to say something today about future granting of farming licenses*".

There have been discussions to whether the current license regime is optimal for the industry. Awarding new licenses is one of the few ways to increase production, which is what the farming companies want when demand is high. Due to limitations, farmers prefer to harvest as much as possible under their MAB restriction, rather than harvesting more market-oriented and smooth. *"We would harvest smoother if we were not bound by the current MAB restriction"* - Tore Holand, general manager in Midt-Norsk Havbruk, commented about smoother harvest of salmon. The limitations associated with the license system have been critiqued, and there have been suggestions to remove the entire system and introduce a supervision act instead. This could result in a smoother harvest that would not be at the expense of utilized capacity, but the disadvantage would be that the farming activities would want to centralize. Production in the north, mainly in Finnmark and Troms, would not be able to compete with production sites like Hordaland where the climate conditions for farming is excellent. The licenses are thus important to ensure geographical separation which at least is biologically favorable. Even if the license system remains "as-is" in the future, the government must acknowledge that the regulations they impose has a direct effect on the price. The price level today, as we have seen in the value chain analysis, is highly destructive for profitability in processing activity.

Capacity limitations in salmon production and growing demand generate high prices. 40 NOK is the new 30 NOK salmon price according to seafood analyst Kolbjørn Giskeødegård from Nordea Markets. Giskeødegård believe that the markets are able to absorb salmon at higher prices than before. The industry has expressed concern for the high price level due to two possible effects; an increasing costs level and increasing international competition. This was explained earlier in this chapter. We asked Bryde if the government share the industry's concern regarding high prices. The government seems to give little thought to the salmon price; "*We are not primarily looking to regulate prices*"- Martin Bryde. However, he does not disagree with the possible effects of the high price level. The government means that the companies' ability to adapt to changing conditions in the industry lays the foundation for further development and hence is a crucial success factor. Since the companies' ability of adapting is not improving with the currently high price level, it is peculiar that the salmon price is of so little interest to the government.

Both the government and the industry agree upon that higher prices trigger competition. Land based salmon farming is an alternative to sea based farming and it could be a realistic competitor in the future. There are already land based plants in the US, Canada and Denmark producing salmon that are branded environmental friendly and completely free of lice. Additionally, the land based plants face little biological risk and no seasonal variation which reduces the production time and facilitates a smoother harvest profile. But there are several obstacles making land based salmon farming difficult, especially if the production plant is located in Norway (Nesse & Næss-Ulseth, 2013). First of all, the investment costs are extremely high for land based farming plants compared to sea based plants. This applies for all production sites. Norway is a high cost country and is not that close to the main markets for fresh salmon. Hence, a lot speak in disfavor of introducing land based farming in Norway. Since the government's main arguments to hold back capacity expansion are the sea lice issue and the risk of escapes, one could wonder if a technology excluding these risks should gain some advantage. According to Bryde, the government wants to maintain technological neutrality and would therefore also require licenses for land based salmon farming. However, he adds that if land based farming were considered as a better and greener technology, new licenses would probably be granted such a production method. If the government wants to "*facilitate growth within sustainable limits*", why should alternatives such as land based salmon farming pay, through licenses, for issues that are non-existing in their production method? The possibility to smoothen out the harvest with land based farming could also participate to more value creation along the coast, another political area of focus. Finally, it is uncovered that if the land based plant were moved to a low cost country closer to the market, it could compete with sea based farming (Nesse & Næss-Ulseth, 2013). Today's salmon price level invites to such initiatives, and it would be wise to take the threat seriously.

6.6.2 Market Access and the EU

About 66% of the fresh salmon exported from Norway goes to the EU.[24] Norway is not part of the EU and hence is not entitled to unlimited market access. Since the late 80's there have been introduced trade protection measures to limit the import of Norwegian salmon to the EU. To prevent these trade protection measures, several farming companies moved parts of their processing activity inside the EU, creating workplaces in Europe.[25] With 30 000 jobs in EU being based on Norwegian farmed salmon, it is important to discuss whether processing of salmon should be pursued in Norway.

"*There is a political agreement that we want to have processing activity in Norway, and also increase processing activity*" – Martin Bryde's comment about value creation along the coastal areas in Norway. First of all, with salmon prices continuing at the current level, it should be debated whether the Norwegian government should maintain life in the Norwegian processing industry when it is so challenging to make it profitable.

Secondly, increasing processing in Norway would possibly create additional value along the coast, but it would imply bringing back jobs from the EU. If the total production of salmon is not increased, there will not be enough raw materials to sustain the European

---

[24] St. Meld. Nr. 22 (2012-2013) Verdens fremste sjømatnasjon

[25] St. Meld. Nr. 19 (2004-2005) Marin næringsutvikling

processing jobs. That the EU would respond to this with economic sanctions is very likely. The Norwegian government specifies a goal to "*Improve the market access to the export markets for fish and fish products, for example through bilateral trade agreements*".[26] In 2005, the government had a similar goal which was to "*work for revocation of political trade measures against import of salmon and trout from Norway to the EU and USA*". To make this happen, the industry was encouraged to build alliances with the processing industry in the markets. Letting the EU take part of the value chain has been an important instrument towards improved market access. With the government now wanting increased processing in Norway, the relationship with the EU could be compromised. When we mentioned this issue for Bryde he explained that impact assessment of this goal has not been conducted.

The salmon industry is regarded of many politicians as an instrument in regional policy to maintain habitation in small coast areas in Norway. This has led to other regulations which cannot be explained by sustainability- or environmental concerns. As the salmon industry is highly international, it requires a competitive cost level as well, which should be considered when the government lays a strategy for more processing activity in Norway. Frank Asche is questioning why we should pursue processing in Norway when we cannot compete on the costs. Today the salmon farming industry is not subsidized in any stages, but with the current governmental goals for the salmon industry, one can question if the need for subsidies might appear.

Political actions and resolutions introduced in Norway could have large impact on the salmon industry. For instance, after the Nobel Peace Prize were awarded Chinese Liu Xiaobo in 2010, the market share of Norwegian fresh salmon in China decreased from 92% to 29%.[27] Similar sanctions could appear, due to political choices made by the government, creating a threat for the salmon industry. The Norwegian Seafood Association (NSL) expresses concerns for such sanctions.[28] NSL acknowledge that Norway, within the framework of the WTO[29] agreement, has a formal option to impose increased import protection. But such an option is available for many other countries as well, among them countries that buy large volumes of salmon from Norway. Such countries can respond with counter-reactions against increased Norwegian import protection on for instance cheese products. The WTO agreement still has room for an increase in the export expenses of salmon products to 35%. These kinds of sanctions will be severe for the Norwegian industry and would not make it favorable neither to process or to introduce processing activity of salmon in Norway.

[26] http://www.regjeringen.no/pages/38500565/plattform.pdf
[27] http://www.dn.no/nyheter/naringsliv/2013/08/16/frykter-langvarig-trobbel-for-norsk-laks-i-kina
[28] http://www.nsl.no/news/90/100/Norsk-bruk-av-tollvern-og-hensynet-til-norsk-sjomatnaring
[29] The World Trade Organization

6.6.3 Environmental Groups and the Media

The salmon industry is affected by pressure of environmental groups. It is therefore important for the industry to be aware of such groups, which may have direct influence in media and consumer decisions.

Due to frequent incidents of sea lice and diseases, the salmon industry is faced with criticism in the media. In Norwegian newspapers one can often find headliners such as "*Must harvest salmon because of disease outbreak*" and "*Not able to stop the ILA infection*". Even as most recently as in May 2014, Midt-Norsk Havbruk was forced to harvest 1.4 million fish due to a disease outbreak called Pancreas Disease (PD), which got a lot of media attention. Such negative attention could have very damaging effect on demand if it appears in the media picture too often. A situation in the French market for salmon illustrates just this fact. Due to a negative article in a major French newspaper and a TV show saying that farmed salmon was dangerous to eat, the French market saw an 18% decrease in salmon imports in 2013, indicating that consumers are sensitive to bad publicity.[30]

An interesting aspect with smoother harvest is that it puts less pressure on the environment. Our model results support this. One can therefore argue that a smoother harvest is more environmental friendly than batch harvesting. The question is if smoother harvest of salmon could be positive for both the environment and reduce biological risk in the production. This could be positive for the industry, especially when certain organizations critique the pressure that salmon farmers put on the environment. Also, innovations such as land based salmon farming and closed containment systems in seawater that shield the production from the environment may be positive for the industry in relation to critique from the media and environmental groups.

[30] Nordea Equity Research: Seafood Sector Update, April 1 2014, by Kolbjørn Giskeødegård from Nordea Markets.

Chapter 7: Conclusion

In this chapter we will determine, based on results from our model and the value chain analysis, if smoother harvest of salmon is in fact favorable for the industry as whole. Our hypothesis is that it is costly for the salmon farmer to harvest smooth, but that smoother harvest would create additional value in other parts of the value chain. The first part of the hypothesis is answered with a quantitative analysis and the second part by a qualitative analysis. Finally, we will consider the importance of smoother harvest in the industry today, compared with other heated issues such as high prices and processing activity in Norway.

By developing a bioeconomic model, we have been able to find the optimal harvesting strategy for cohorts released in different times of the year, given batch- and smooth harvest. The profit indeed decline when harvest occurs at a smooth rate over the year compared to batch harvesting, confirming the first part of our hypothesis. The losses of harvesting smoother are respectively 8.4% and 9.1% given the estimated and the constant price. Interestingly is the fact that the losses are larger if the underlying price is constant and not variable. This would make the incentives to harvest smoother smaller as the degree of smooth harvest increases in the farming stage of the industry. Developing a bioeconomic model is a difficult task, as there are many real life phenomena to take into account. In order to make the model feasible, several assumptions have been made. The most discussed simplification is the absence of seasonal variation. Many academic papers also disregard this impact in their models, but after having talked to several players in the salmon industry we are convinced that seasonal variations in fact have a huge impact on the growth of the fish.

In addition to the model, we have investigated the potential effects of a smoother harvest of salmon through a value chain analysis. We have been in contact with different agents in the value chain and tried to identify how a smoother harvest may have an impact on them.

An important question to make is, as long as smoother harvest is more costly than harvesting a couple of times per year, will independent farmers have any incentives to implement such a harvest strategy? It does not seem to be profitable for the farmer to harvest smoother today; otherwise they would have already harvested smoother. According to our value chain analysis, some salmon farmers would like to harvest smoother, but due to different production restrictions, this is very difficult. For instance, Midt-Norsk Havbruk would produce 22% less daily if they were to produce strictly smooth over the year. This is due to bad utilization of the MAB limit. Additionally, the biology in the production will always be a decisive and partly uncontrollable factor the farmer must adapt the harvest after. For instance, unexpected disease outbreaks can occur any time, making noises in the salmon supply curve. A company only pursuing farming activity does not have strong incentives to harvest smoother. Naturally, the company's objective is to make money, and with the market being undersupplied, the company's harvest strategy has no practical impact on whether they are able to sell all their fish or not. Hence good profits will be gained no matter what happens downstream in the value chain, and the company does not need to please the processors with smooth deliveries as their benefit does not depend on the processors well-being. For a vertically integrated salmon farmer the harvest strategy must take into consideration what is optimal for the next stage, thus the processors. Therefore, incentives to harvest smoother augment, as the company would like to fully utilize capacity in the processing facilities. It seems like the only reason for why large vertically integrated companies cannot harvest completely smooth, is bound by the biological nature of the production process, making us question if a complete smooth harvest is feasible at all in a country such as Norway with large seasonal variations.

According to our analysis, the processors seem to be the part of the value chain which would highly benefit from smoother harvest, since it would to some degree also smoothen out the price. The processors are exposed to risk on the input side and more trade over forwards contracts and less on the spot market would be favorable for their activity. As independent processors struggle with large price variations and thus profit variations, they are squeezed between two large agents; the farmers and the retail chains. But the value chain analysis indicates that the high salmon prices are of a larger concern for the processors than unstable supply. Mergers and acquisitions have left only a few independent processors in Norway. It looks like this trend will continue, and the independent processers are really concerned for their future existence in the Norwegian salmon industry if high prices maintain. We hence conclude that smoother harvest itself would not solve the challenges that the processors are facing in the current market, but it would facilitate the processing activity.

An interesting finding from the value chain analysis is that it does not seem like retail chains are affected by unsmooth supply. REMA 1000 for instance, mention that the only periods they experience lack of supply is after holidays. This indicates that the farmers aim to saturate the Norwegian market before exporting fish, making this market practically unaffected by the harvest strategy of the farmer. The international market however, may be more affected. Another interesting finding is that the shelf prices which the consumer has to pay, never has reflected the high HOG prices of salmon traded on the spot marked. With the prices remaining high, the consumer must be willing to pay a larger amount and the issue of demand destruction is brought up. With consumers being used to having salmon products available at stable prices at all times, a sharp increase in prices may have severe consequences for the retailers. Hence, for the Norwegian retailer, the high price level is more challenging than a non-smooth harvesting profile.

The industry today seems to share larger concern for the high price level rather than the current harvesting profile. The high prices are a result of growing demand and lack of farming licenses issued by the government. Our analysis has revealed two unfortunate effects of high prices. First of all high prices may trigger competition in other countries. High prices indicate attractiveness in the industry, giving incentives for others to develop new farming technologies, such as land based salmon farming. Despite high investments cost, even land based salmon farming can experience good margins when salmon prices are on 2013 levels. The analysis also reveals another important issue, which is that cost levels usually tend to rise in times with high prices. This could be very damaging for the salmon industry in the long run, as high prices weakens the salmon farmers' ability to adapt. Is the trend of high prices likely to turn any time soon? We do not believe that the industry will see a predictable growth during the next years. According to the Department of Trade, Industry and Fisheries, no new licenses, and hence no new capacity, will be issued in the near future. This is kind of a paradox as one of the main objectives of the government is to facilitate a 3-5% yearly growth in the industry.

The government wants more value creation in coastal areas, meaning that they want more processing activities to take place in Norway. We find it very strange that the government in fact wants to facilitate a more market oriented production of salmon, thus a smoother harvest profile, while at the same time they do not issue new capacity. First of all, we believe that by facilitating more processing activity in Norway, the salmon industry will meet higher trading barriers to the EU, since it would compromise European processing jobs. Destructive sanctions would likely be the result, and therefore we question if the government's objective to process more salmon in Norway really is thought out.

Changing the current MAB regime to a rolling MAB is an example of one measure that the government are considering to implement to facilitate Norwegian processing, but one can question if this will even have an effect with the salmon prices being at such high levels as it is today. As long as the government do not issue more licenses, their objective of facilitating more processing and value creation in Norway is very difficult to fulfill. A smoother harvest would not change that, and the government claims that for all activity pursued in Norway, the foundation is always profitability.

In summary, we do not believe that salmon farmer's losses by adapting a completely smooth harvest profile would be regained through other parts of the value chain. A smoother harvest would be beneficial in terms of more processing activity and more value creation. Based on results from our model, we also conclude that a smoother harvest may reduce some of the biological pressure salmon farming put on the environment. However, we have uncovered that the high price level is a lot more destructive for the industry, and that smooth harvest would not solve this issue. The high prices however could result in emerging technologies such as land based salmon farming, that are able to deliver smoother supply of salmon, unlike the industry today.

Chapter 8: Critique of the Model and Future Work

In the following, we will discuss limitations of the model presented in Chapter 3 and the assumptions taken in Chapter 4. Also, recommendations for future work and a new hypothesis are suggested.

8.1 Critique of the Model

The results from our model provide an insight into optimal harvesting for a farming company. However, it also excludes a number of real world phenomena, most importantly seasonal variation. These variations will most likely affect the fish growth, production costs and mortality rate. Further simplifications have been made in relation to price estimations, regulations and discount rate, which might be factors affecting the production more than we have accounted for in our model.

In the model, we have assumed that production costs are constant figures. In reality, production costs may vary with the seasons. In the winter, when the sea water is cold, the fish convert feed at a lower rate, resulting in higher feed costs. The fact that production costs are higher in the winter months could trigger harvest before winter sets in. In addition, in the north of Norway where climate conditions become very cold and rough during winter months, the risk of equipment being damaged and escape occurring are higher during winter. These effects are not accounted for in the model.

It is critique worthy that we have based our results on two cohorts of fish that follow the same weight function independent of when the cohorts are released to sea. In reality, due to lower sea water temperatures in the winter months, the fish usually grow at a slower rate in these months. The opposite effect applies for warmer months. By disregarding seasonal variations, the model may generate lower biomass values in certain months than it would in reality, meaning that the profits could look different if seasonal variations were included. If one were to model the weight curve in a more realistic manner, one could take into account feeding regime, density of the fish in the net pen, sea temperature, the hours of light per day, salt level and other biophysical factors.

The salmon farmers are restricted by regulations that limit production. In the model, the MAB limit is not accounted for, since we wanted the relationship between batch and smooth harvest. If we were to include the MAB limit, it would restrict the biomass to always be lower than 780 tons for one license and we would have optimized the smolt release, and not optimal harvest strategy. A downside by not including the MAB limit is that the MAB limit may trigger harvest, which could make our results look different. But since we are investigating a distribution problem in combination with optimal harvest time, it is more important for us to be able to distribute harvest equally each month than to restrict harvest to the MAB limit.

The fact that we use the same price for the different salmon sizes could be critiqued. In reality, farmers gain different prices for different sizes of fish, an aspect we have not accounted for in the model. As prices for different weight classes could change the biomass value, it is relevant for the optimal harvest time. However, since the processors preferred weight class for salmon is between 3-6 kg, and our harvested fish lies within this range, the relative price differences is not that significant. The large price discounts or premiums applies for fish weighing below 3 kg and fish weighing above 7 kg, and these sizes are not relevant in our analysis.

In the model, we have assumed a mortality rate of 1% monthly on average. In reality, the mortality rate could be very different. For instance, under normal circumstances, the highest mortality rate will be observed during the first 1-2 months after the smolt is put into seawater, while subsequent stages of the production cycle normally has a lower morality rate (Marine Harvest, 2013).

We have chosen a discount rate of 9% for the company we are investigating. This discount rate is estimated mainly based on the size of the company. We assume that the company in question is a mid-sized farming company, but since we only assume a production with two cohorts of fish, one could argue that the company is of a smaller size. In reality, for a small sized company a higher discount rate of 10% could be a more suitable measure to apply. Moreover, in a situation where a small sized company pursue batch harvesting, one can argue that there are linked more risk to the production, meaning that a higher discount rate should be applied.

A final remark is that a lot of the parameter values used to generate results from our model was decided before we talked to the players in the value chain. Thus many of the aspects we criticize here have been discovered late in the thesis process. However, we believe that the parts lacking quantitative specification in the results, such as seasonal variations, still has been considered through a qualitative approach.

8.2 New Hypothesis and Future Work

Among our concluding remarks in this thesis is that the high prices are an issue of more concern than the current non-smooth harvest. Due to limited capacity in salmon farming production, the prices of salmon are expected to be high in the years to come. With high salmon prices, processing in Norway will probably not be profitable to operate in the near future. Hence the total industry requires growth to maintain its leading position in an international seafood market. Based on these findings we have stated a new hypothesis that could be interesting to investigate:

The current lack of a predictable growth strategy from the government compromises the Norwegian salmon farming industry's leading position in an international market.

Investigation of the new hypothesis should to a large extent include how the government could facilitate more growth in the salmon industry. This could be done by investigating industry views, and also investigate effects of different regulations regimes. The standing suggestions to ensure growth in the future are to increase the MAB limit or to issue more farming licenses, but nothing is decided yet. The government is the important decision maker for further growth, and they must realize their dominant role for the Norwegian salmon industry's well-being. Furthermore, one could look at the possibilities of new technologies being suitable for salmon farming in Norway, and how the government could regulate those technologies.

Bibliography

Andersen, T., Roll, K. & Tveterås, S., 2008. The price responsiveness of salmon supply in the short and long run. *Marine Resource Economics,* Volume 23, pp. 425-437.

Asche, F., 2008. Farming the sea. *Marine Resource Economics,* Volume 23, pp. 527-547.

Asche, F. & Bjørndal, T., 2011. *The Economics of Salmon Aquaculture.* s.l.:Blackwell Publishing Ltd.

Asheim, L. J. et al., 2011. Are prices or biology driving the short-term supply of farmed salmon?. *Marine Resource Economics,* Volume 26, pp. 343-357.

Bjørndal, T., 1988. Optimal Harvesting of Farmed Fish. *Marine Resource Economics,* 5(2), pp. 139-159.

Cacho, O. J., 1997. Systems modelling and bioeconomic modelling in aquaculture. *Aquaculture Economics & Management,* Volume 1, pp. 45-64.

Forsberg, O. I., 1999. Optimal harvesting of farmed Atlantic salmon at two cohort management strategies and different harvest restrictions. *Aquaculture Economics & Management,* 3(2), pp. 143-158.

Løland, A. et al., 2011. Prediction of biomass in Norwegian fish farms. *Canadian Journal of Fisheries and Aquatic Sciences,* Volume 68, pp. 1420-1434.

Marine Harvest, 2013. *Marine Harvest Industry Handbook,* s.l.: s.n.

Nesse, A. G. & Næss-Ulseth, F., 2013. *Valuing Land Based Salmon Farming as a Real Option,* Trondheim: Norwegian University of Science and Technology - NTNU.

Rosten, T. W. et al., 2013. *Land Based RAS and Open Pen Salmon Aquaculture: Comparative Economic and Environmental Assessment,* s.l.: SINTEF Fisheries and Aquaculture, The Conservation Fund Freshwater Institute.

Skonhoft, A., 2012. The maximum economic yield management of an age structured salmon population. *Models of the ecological hierarchy,* pp. 101-110.

Strand, P., 2014. *Salmon Market Update,* Oslo: SEB.

Torrissen, O. et al., 2013. Salmon lice - impact on wild salmonids and salmon aquaculture. *Journal of Fish Diseases,* Volume 36, pp. 171-194.

Appendix

A.1 Mathematical Representation of the Beverton-Holt Model

Mathematical representations of population dynamic fundamentally describe the process by which the number of individual within a population increases as a function of reproductive rate and decreases as a function of mortality rate. In salmon farming, the reproductive rate of a population can be equated with a one-time introduction of salmon smolts into seawater. Together, these smolts form a cohort.

In the model we make use of a Beverton-Holt model that represents the rate of change in the number of fish for a single cohort.

At time equals zero, the following applies,

$$N(0) = R$$

At time equals zero , the initial number of fish in the sea pen, denoted by N_0, is equal to the amount of smolt released into the sea called recruits, denoted by R.

According to the Beverton-Holt model (Asche & Bjørndal, 2011), the rate of change in fish numbers of a population is given by,

$$\frac{dN}{dt} = N'(t) = -M(t)N(t)\,, \qquad 0 \leq t \leq T$$

$$N(t) = Re^{-\int_0^t M(u)du}$$

In the Beverton-Holt model, the variable t measure the time elapsed since the release of fish in seawater. The changes in the number of fish will occur between seawater entry time, denoted by t_0, and sexual maturation at time, denoted by T. The rate of change in the number of fish is a function of the mortality rate, denoted by M, over time. In the model, N_t represents the population remaining at time t. By assuming that the mortality rate is constant, the number of fish in the population at time t is given by,

$$N(t) = Re^{-M(t)t}$$

In a discrete setting, the number of fish can also be expressed as,

$$N_t = N_{t-1}(1 - M_t)$$

A.2 Estimated Price for May Fish and October Fish

Production month	Estimated price, May release	Estimated price, October release
12	43,67	40,19
13	43,95	39,26
14	42,79	38,91
15	42,31	41,07
16	41,67	40,13
17	40,19	40,82
18	39,26	42,10
19	38,91	43,67
20	41,07	43,95
21	40,13	42,79
22	40,82	42,31
23	42,10	41,67