
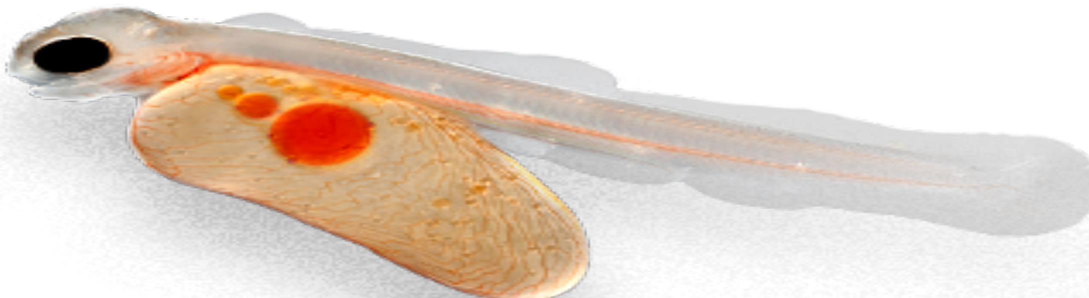

SALMON ECONOMIC ANALYSIS

AN OPERATIONAL COST STUDY, FINDING BETTER WAYS TO ENSURE EFFICIENT RESOURCE UTILIZATION, IMPROVES PROFITABILITY AND ENVIRONMENTAL SUSTAINABILITY FOR THE SALMON AQUACULTURE IN NORWAY.

by

Md Fazla Rabbi Alam

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ABSTRACT

Salmon aquaculture is the fastest growing industry in Norway, contributing to food security and nutrition. The industry ensures social, economic and environmentally sustainable development by utilizing natural resources efficiently. However, this industry consistently encounters challenges; idle capacity, pollution, diseases, parasites and fish escaping, to name a few. The considerably longer production cycle is largely responsible for brewing these challenges. Moreover, these limitations have elevated the concern about the significant economic losses and ecological impacts. With the current technologies, under current regulatory and ecological conditions, despite increasing salmon demand in the global market, room for industrial growth is constrained. This has led to an increase of a significant attention in the area of new technology development and new ways for sustainable expansion.

A number of variables determine profitability in aquaculture, including capacity utilization, biological factors, capital investment, operational costs and sales price. Many of the actual outcomes in the aquaculture rely on the efficient usage of MTB (Maximum Total Biomass) limit, which is considered the most scarce and expensive resource for a fish farm production.

The current study has undertaken economic analysis to assess the MTB utilization and cost of production in the current production model of a traditional sea-based salmon farm situated in Sognefjorden. The report aims to investigate how the current MTB limit is utilized and how time, information and uncertainty can create incentives or difficulties for improving MTB usage during the "post-smolt" production phase. A shorter production cycle possibly improves production capacity utilization and production turnover to ensures "economies of scale". Thus, production time is reduced, adopting policies like introducing larger smolt compared to the regular smolt and optimal harvesting weight class. Hence, the shorter production cycle ensures efficient resource utilization, reduce vulnerabilities, higher production volume, lower production costs and improve profitability.

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EVERYDAY, 14 MILLION MEALS CONSUME NORWEGIAN SALMON AROUND THE WORLD

1. INTRODUCTION

Fish is predominantly getting popular to fulfill the need of animal protein. Faster growth in the world population has triggered per capita fish consumption significantly. Between 1961 and 2016, the average annual increase in global food fish consumption (3.2 percent) exceeded that of meat from all terrestrial animal combined (2.8 percent) (FAO State of World Fisheries and Aquaculture, 2016). At the same time, natural fishery production has been relatively static. To fulfill upcoming global fish demand, aquaculture farming is a popular alternative to traditional capture fisheries. Aquaculture is "the farming of aquatic organisms" (Timmons & Ebeling, 2002). It allows increasing production without stressing out the marine ecosystem or further exploitation to the wild fish stock. Aquaculture has been shown an impressive growth in the supply of global fish consumptions over the last decades and is expected to continue. By 2030, 62% of the global fish supply is projected from aquaculture farming. Aquaculture production is likely to be the main source of fish on the global market by 2050 (FAO, 2014; World Bank, 2013; Forrester & Senge, 1979; Sterman J. , 2000)

Norway is considered to be one of the prominent players in the global fish market. The country has flourished in the salmon aquaculture. It has a long coastline and historical fishing legacy. Fish has always been a major source of food and income for the Norwegian society. But it has become a prime contributor for the Norwegian economy since the aquaculture has formally adopted in 1970. A steady growth for Norwegian fish industry has been observed since then. The demand for the Norwegian fish is in an increasing trend, where Atlantic salmon is accounted for 94% of the total production (Norwegian Ministry of Trade, 2014) Salmon aquaculture is mostly carried out along the coastline. These farms are simply constructed for large production volumes with relatively moderate investment.

Nevertheless, this industry consistently encounters challenges, not limited to, idle capacity, pollution, diseases, parasites and fish escaping. These have elevated the concern about the surge in production costs and ecological impacts.

A number of variables determine profitability in aquaculture, including capacity utilization, biological factors, capital investment, operational costs and sales price. Many of the actual outcomes in the aquaculture, rely on ensuring a healthy environment and efficient MTB limit utilization. The current study has undertaken an economic analysis of a traditional sea-based salmon farm situated in Sognefjorden. The study assesses the current status of MTB utilization, production duration and production cost to identify the leverage point in the current production model. The report aims to explore ways to improve the current resource utilization, control the production cost and create economic incentives for the farm. Thus, a cost analysis study is conducted to appraise whether and how production duration, resource utilization and profitability are interconnected.

A fish farm's profitability largely depends on its resource management and operational efficiencies (Bjørndal & Tusvik, 2016) (Osland, 2018). Operational spending decisions are more frequent than the capital investment in this industry. Increase in operational efficiencies improves productivity; thus helping the business remains profitable. So an operational economic analysis is a key to anticipate the direction of the business growth. Thus, an exploratory simulation model has been constructed to replicate the production cycle and to reproduce results from the provided information and data. Once replicated, simulated results provide a better understanding of the underlying dynamics of the system. Through experiment and analysis, the model discovers the potential sources of problems. It is perceived those problems are latent under the longer production cycle and inefficient MTB utilization. To improve capacity utilization and reduce production time, two promising policies regarding smolt and harvesting are tested as tentative solutions. By introducing larger smolt and early harvesting policies, production time is fairly reduced, capacity utilization is improved and production volumes are significantly increased that help to achieve the "economies of scale". During the experiment it is observed, a policy in one sector has a significant influence on the other sectors. The key to deciding the best suitable policies is to consider the intensities of the influence. However, the model reveals a coupling between the two policies to obtain the best possible outcome.

The thesis is outlined as follows. Chapter 1 presents background and challenges in the salmon aquaculture industry. Chapter 2 gives an overview of the model. Chapter 3 focuses on the model analysis, testing and validation. Chapter 4 discusses different policies and effects. Chapter 5 summarizes the research findings.

2. MODEL OVERVIEW

This is a collaborative effort to replicate the salmon production model and suggesting policies to improve the existing production process based on a real salmon aquaculture farm in Sognefjørden. The model is integrated with several smaller models that interact. The final model is divided into two main sections based on the fish biology and fish economy. The integrated model is comprised with three main sections. They are

1. Production and Growth sector.
2. Lice sector. and
3. Economic sector.

First two sectors, known as the production sector are developed based on the fish biology, describing factors involved in the aquaculture production process. This sector highlights the ideal conditions for fish to thrive and obstacles that limit them to prosper.

This production model recreates the core production operations of the fish farm, showing the biomass growth in pre-smol stage; how smolts are distributed to different production sites, total produced biomass and slaughtering conditions. This is the foundation of other sub models. The second biological sub model is sea lice infestation model that shows the different lifecycle of sea lice, how sea lice build up with the growing biomass and accumulating effects on their surroundings. Based on these two sub models an economic model is developed, demonstrating the total revenue, expenses and profit of the farm. The economic sector keeps track for production costs and helps farmers to visualize the benefits of different policies.

Production and Growth Model Description

Production and growth model is considered as the center of the entire model, describing the aquaculture production and growth operations run by Osland Havbruk AS. The model is run over for 5 years (1817 days) period, starts on January 1st. The overview of the salmon production and growth sector is taken from the paper **"Public Policy Improvements to Norwegian Salmon Aquaculture Operations – A Case Study "** (McConnell , 2018)**.**

Assumptions and limits of the production and growth sectors

There are a number of assumptions built into the sectors of the model, explained below.

Juvenile Growth Sector

Osland Havbruk produces their own fry, and the fry can remain at a small size, under 2g, by being kept at 7 degree and fed minimally (Osland, 2018). For this reason, the model assumes that Osland Havbruk always has the capacity and ability to produce as many smolt from their stock of fry as they need, at any given time. The process of smoltification (transforming the freshwater parr into saltwater smolt) is not included in the model. This process takes place during the last stage of parr growth, and when it takes place is decided by the farmer. As it has no effect on the growth of the parr, it has been omitted from the model.

Juvenile Feeding Sector and Fish Feeding Sectors

As Norwegian law states that aquaculture operations should have acceptable water quality, including among other factors levels of water circulation, dissolved oxygen, and algae, (Bruland , 2016) the assumption has been made that these variables are within acceptable limits and are outside of the boundaries of this model.

The feed conversion ratio, (the amount of food needed to produce one unit of growth) changes over a fish's lifetime. Fish appetite is also dependent on many factors, including fish size, time of day the fish are fed, and access to light (Bolliet, Azzaydi , & Boujard, 2001) For simplicity's sake, the feed conversion ratio has been set to an average over the fish's lifetime, rather than changing with the size of the fish, and the assumption has been made that the fish eat all the food they are given.

It is also assumed that the fish are all exactly the same weight, where in reality there would be some variation in fish weight within a cohort. There are methods, such as "grading" (separating the larger fish from the smaller ones) which minimize the variation in parr and fish size (Stead & Laird, 2002). The stocks of "parr weight" and "fish weight" can then be thought of as an average weight of one fish in the cohort.

Sea and Slaughter Sector

The model assumes that there is always available capacity to slaughter. Osland Havbruk contracts slaughter to an outside company, who provide their own boats and equipment (Osland, 2018). Whether or not boats are available is out of the control of the fish farmer, and outside of the limits of the model. The model assumes a fixed mortality rate in this sector. Usually, there is higher fish morality in the 1-2 months after the smolt have been introduced to sea (Marine Harvest, 2017). But with a lack of data on the magnitude of this change, the model uses a fixed mortality rate.

Juvenile Growth Sector

Osland Havbruk does not buy smolt from another company, but instead produces its own smolt from fry. They have three rooms in which they grow the fry from parr to smolt in tanks. To reflect this set-up, the juvenile growth sector is built to match the physical facility. The capacity of fry, parr and smolt in the rooms in the model does not exceed the capacity of the facility.

Figure 1: Salmon fry

Figure 2: Tanks where salmon fry are kept

Figure 3: Tanks in room 1	*Figure 4: Tanks in room 2*

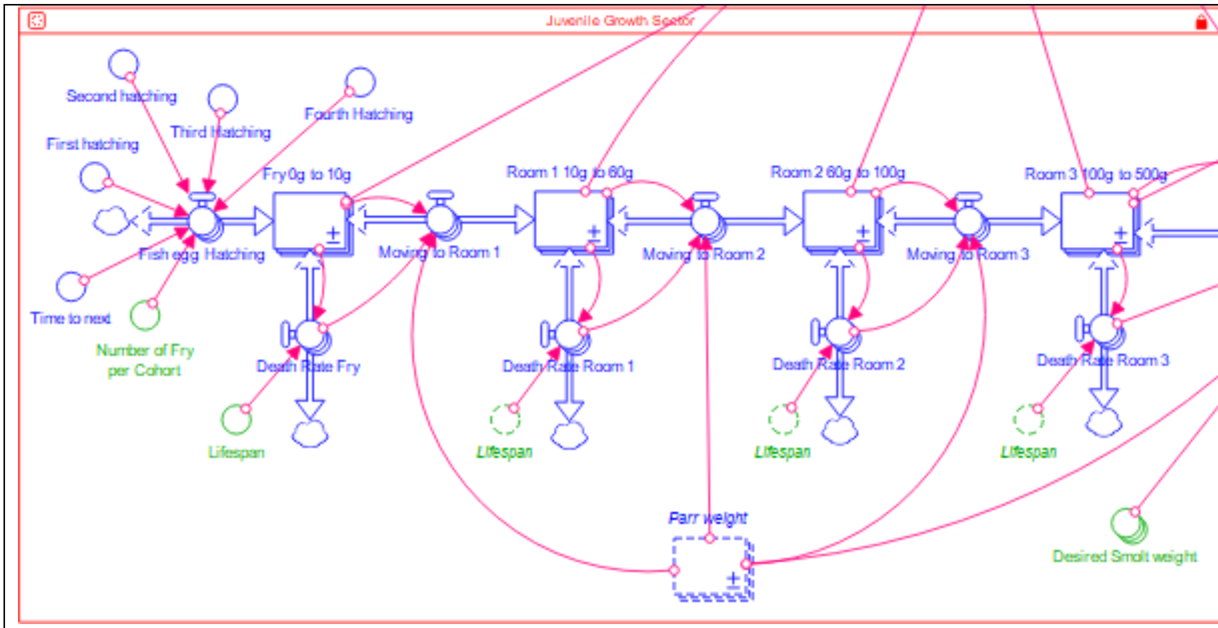


Figure 5: Juvenile Growth Sector

This sector is an aging chain, with arrays. There are four cohorts, one for each location Osland Havbruk has in the sea. The "number of fry per cohort" is the maximum amount allowed at one location at sea with 6 cages – 1 200 000 (Bruland , 2016)– plus the amount expected lost due to the natural death rate – 20 fish per day over approximately 240 days (Osland, 2018) – and is set at 1 205 000.

Fish farmers put their cohorts out to sea at two different times of year: spring and autumn. The fish take around 240 days to grow to the reference mode "desired smolt weight" of 250g. The introduction dates, therefore, are 240 days before the time when the farmer wants to put the smolt into the sea. The equation for hatching is then a pulse function which transfers the "number of fry per cohort" at the chosen "hatching" time, and repeats based on the value of "time to next hatching".

Hatching[*n*] = Pulse (Number of Fry per Cohort, [*n*]Hatching, Time to next hatching)

The fry then remain in the "Fry 0g to10g" stock until they have reached 10g. Their weight gain is shown in the next sector, Juvenile Feeding Sector. Once this sector indicates that the fry are at the maximum weight for the room, a pulse function moves them to the next room, "Room 1 10g to 60g". From this room onward, the fry will be called parr.

This pattern continues for rooms two and three; when the maximum weight in the name of the room is reached, the parr are moved to the next room. Each room also has a lifespan of 60000 days, which corresponds to a death rate of 20 fish per day.

Juvenile Feeding Sector

The Juvenile Feeding Sector is based on a reinforcing loop where the "amount of food fed per day" is a percentage of the "parr weight", and this amount changes based on the "temperature" of the water and the size of the parr being fed.

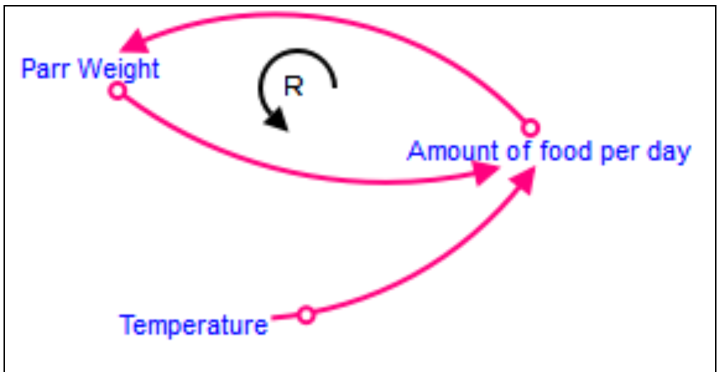


Figure 6: Juvenile growth re-enforcing loop

The complete sector, with arrays, is seen below.

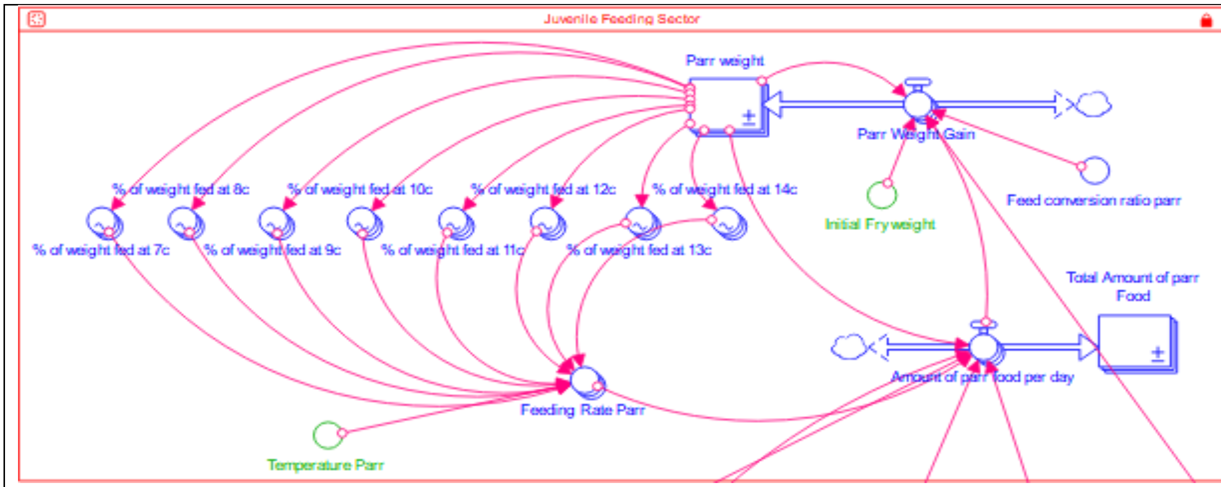


Figure 7: Juvenile Feeding Sector

Osland Havbruk grows their parr to smolt from fry (when the salmon have just hatched and left the egg sac), so the "parr weight" stock is initialised with an "initial fry weight" of 0.2g. The parr then gain weight based on the "amount of parr food per day", divided by the "feed conversion ratio parr".

The feed conversion ratio is the amount of input (food), which produces one unit of output (growth). It is impossible for 100% of the food fed to the parr to go towards growth; some of it is expended through other biological processes. Fish food has become very refined over the years, and Skretting AS, the food producer which Osland Havbruk uses, calculates that based on their best current practices, they have a feed conversion ratio for Atlantic salmon of 1.15 (Skretting.com, 2018) – that is, it takes 1.15 units of food to produce 1 unit of weight.

The first part of the "parr weight gain" equation ensures that there are parr to feed in Juvenile Growth Sector and also resets the parr weight once a cohort has left the Juvenile Growth Sector, by going through the "to sea" flow which connects this sector to the Sea and Slaughter Sector. The second part of the equation feeds the parr.

Parr Weight Gain[Cohorts] = IF To Sea[Cohorts,1] > 0 OR To Sea[Cohorts,2] > 0 OR To Sea[Cohorts,3] > 0 OR To Sea[Cohorts,4] > 0 THEN (-Parr weight + Initial Fry weight)/DT ELSE Feed conversion % parr*Amount of parr food per day

To decide the flow “amount of parr food per day”, the “feeding rate parr”, is taken, divided by 100 and multiply it by “parr weight”, so that the amount of food fed is a percentage of the body weight of the parr. This formula also has a mechanism in the beginning to ensure that there are parr in the rooms before they are fed:

Amount of parr food per day[Cohorts] = IF Fry 0g to 10g > 0 OR Room 1 10g to 60g > 0 OR Room 2 60g to 100g > 0 OR Room 3 100g to 500g > 0 THEN (Feeding Rate Parr/100)*Parr weight ELSE 0

The “feeding rate parr” then depends on the temperature and the “percentage of weight fed at Xc” variables. This structure is based on the growth chart by the feed producer Osland Havbruk uses, Skretting AS (Skretting Fôrkatalog, 2012). This chart gives the amount of growth, as a percentage of bodyweight, that the parr gain at a given temperature. When this growth is multiplied by the above mentioned feed conversion ratio of 1.15, the amount of food needed to produce this growth is calculated. The original charts can be seen on the next page.

In room three, the parr undergo smoltification (the change from living in fresh water to living in seawater) and are now called smolt. Osland grows their smolt to between 150g and 250g, which is larger than the size of smolt grown by traditional producers (between 50g and 80g) (Stead & Laird, 2002). This is to reduce the amount of time the fish spend in the sea, where temperatures are often lower, growth is slower, and the risk of disease or accidents is higher. The growth tables provided both for parr and fish (salmon) have been combined to create the graphs used in the model.

Settefisk

Laks

Tilvekst (% per dag) laks settefisk, basert på ClubN 2009

Forventet daglig tilvekst i ulike vekstintervaller

°C	Startf.–1 g	1–5 g	5–15 g	15–30 g	30–60 g	60–100 g
1	0,41	0,35	0,17	0,12	0,07	0,04
2	0,82	0,69	0,38	0,28	0,20	0,12
3	1,23	1,04	0,59	0,44	0,32	0,21
4	1,65	1,38	0,80	0,60	0,44	0,30
5	2,06	1,73	1,01	0,76	0,56	0,39
6	2,47	2,07	1,22	0,92	0,69	0,47
7	2,88	2,42	1,43	1,09	0,81	0,56
8	3,29	2,76	1,64	1,25	0,93	0,65
9	3,70	3,11	1,85	1,41	1,05	0,74
10	4,11	3,45	2,06	1,57	1,17	0,82
11	4,52	3,80	2,27	1,73	1,30	0,91
12	4,94	4,14	2,48	1,89	1,42	1,00
13	5,35	4,49	2,69	2,05	1,54	1,09
14	5,76	4,83	2,90	2,21	1,66	1,17
15	6,17	5,18	3,11	2,38	1,78	1,26
16	6,58	5,52	3,32	2,54	1,91	1,35
17	6,99	5,87	3,53	2,70	2,03	1,44

Figure 8: Parr, Salmon. Growth (% per day) salmon parr, based on ClubN 2009. Expected daily growth for different growth intervals

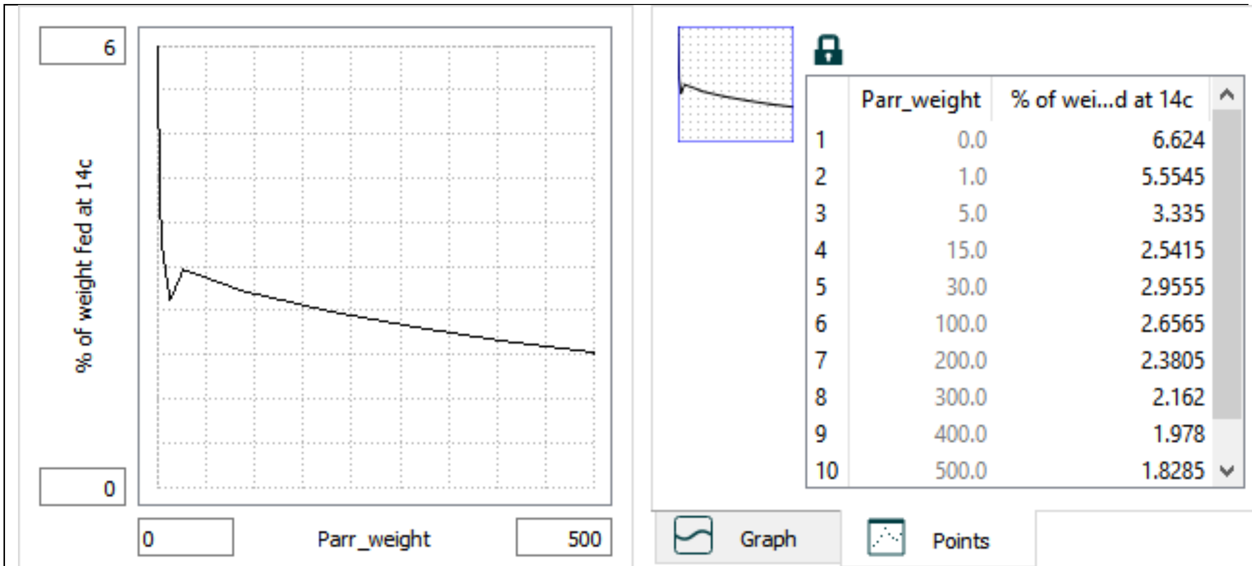
Atlantisk laks

Tilvekst (% per dag) og biologisk fôrfaktor for atlantisk laks (basert på resultater fra Skretting R_{max}-databasen)

	Temperatur (°C)																					
gram	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	bFF*	Akk. bFF*
30	0,17	0,33	0,51	0,70	0,89	1,09	1,29	1,49	1,69	1,89	2,08	2,26	2,42	2,57	2,68	2,75	2,78	2,74	2,63	2,42	0,81	0,81
100	0,12	0,29	0,48	0,67	0,86	1,06	1,25	1,44	1,62	1,79	1,95	2,09	2,21	2,31	2,38	2,41	2,39	2,32	2,18	1,98	0,81	1,16
200	0,12	0,28	0,45	0,62	0,80	0,98	1,15	1,32	1,49	1,64	1,77	1,89	1,99	2,07	2,12	2,14	2,12	2,05	1,93	1,75	0,82	0,96
300	0,11	0,25	0,41	0,57	0,73	0,90	1,06	1,21	1,36	1,49	1,61	1,72	1,81	1,88	1,92	1,94	1,91	1,85	1,74	1,57	0,83	0,91
400	0,10	0,23	0,37	0,52	0,67	0,83	0,97	1,12	1,25	1,37	1,48	1,58	1,66	1,72	1,76	1,77	1,75	1,69	1,59	1,44	0,84	0,89
500	0,09	0,21	0,34	0,48	0,62	0,77	0,90	1,04	1,16	1,27	1,37	1,46	1,54	1,59	1,63	1,63	1,61	1,56	1,47	1,32	0,84	0,88

Figure 9: Atlantic Salmon. Growth (% per day) and biological food conversion for Atlantic salmon (based on results from Skretting R database).

Standard industry practice, which Osland Havbruk follows, is to grow parr at 14c (Stead & Laird, 2002), so "temperature parr" is set to 14c. This means that under reference mode conditions, only the converter "% of weight fed at 14c" is used when running the model, however other temperatures were included in order to allow for experimentation with growing the parr to smolt at different temperatures. The graph showing the feeding percentages at 14c is below.



	Parr_weight	% of wei...d at 14c
1	0.0	6.624
2	1.0	5.5545
3	5.0	3.335
4	15.0	2.5415
5	30.0	2.9555
6	100.0	2.6565
7	200.0	2.3805
8	300.0	2.162
9	400.0	1.978
10	500.0	1.8285

Figure 10: Graph and values of parr feeding levels at 14c up to parr weight of 500g. Graph is a product of Skretting's tables multiplied by the food conversion ratio.

Fish Feeding Sector

The fish feeding sector is similar in structure to the juvenile feeding sector. It too is based on a reinforcing loop where the "amount of food fed per day" is a percentage of the "fish weight", and this amount changes based on the "temperature" of the water and the weight of the fish.

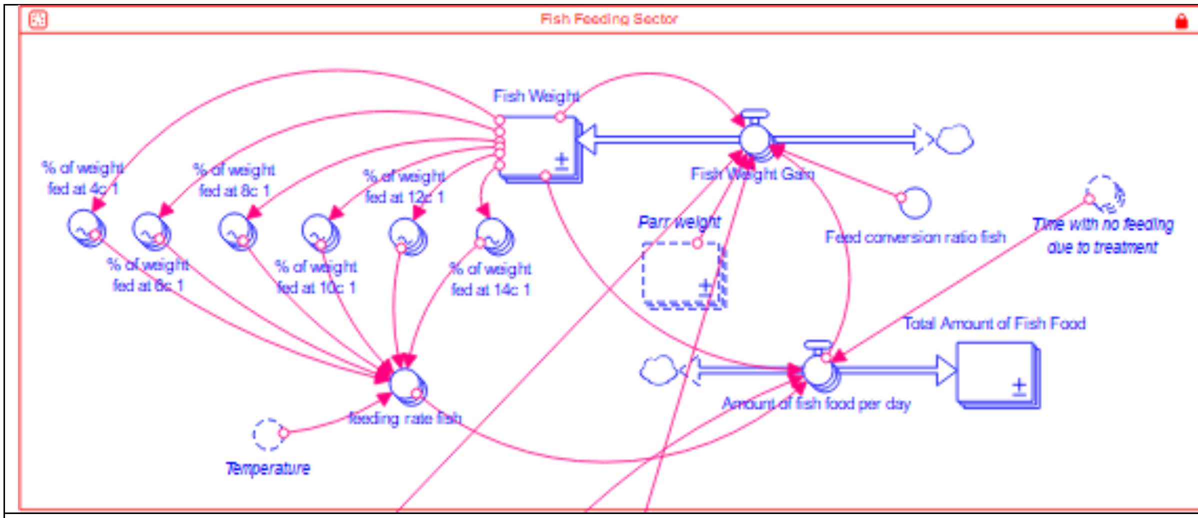


Figure 11: Fish Feeding Sector

The "fish weight" stock is initialised at 0, and the flow "fish weight gain" is based on the "amount of fish food per day", divided by the "feed conversion ratio". This inflow too has a condition that prevents the model from feeding the fish if there are no fish in the cages at sea, and resets the fish weight to 0 when the fish are slaughtered.

Fish Weight Gain [*n*] = IF To Sea[*n*,*n*] > 0 THEN (Parr weight[*n*])/DT ELSE IF Weight Slaughter[*n*] > 0 THEN (-Fish Weight[*n*]/DT) ELSE Amount of fish food per day/Feed conversion ratio fish

The flow of "fish food per day" is dependent on the "fish weight" and the "feeding rate fish", as long as there are fish in the sea cages, and as long as the fish are not being treated for lice. If the fish are undergoing treatment for lice, then they cannot be fed for 5 days before the treatment has starts (Robb, 2008). The times when they are not being fed are calculated in the lice treatment sector, and "time with no feeding due to treatment" is simply a switch that turns on and off feeding in this circumstance.

Amount of fish food per day[*n*] = IF Locations[*n*] >100 AND Time with no feeding due to treatment[*n*] = 0 THEN feeding rate fish/100*Fish Weight ELSE 0

The "feeding rate fish" is dependent on the temperature. In the sea, temperatures can vary widely depending on the season. Historical temperature data, provided from

Osland Havbruk for the Sognesjøen, Ytre Sogn region has been used in this model, and repeated over 5 years.

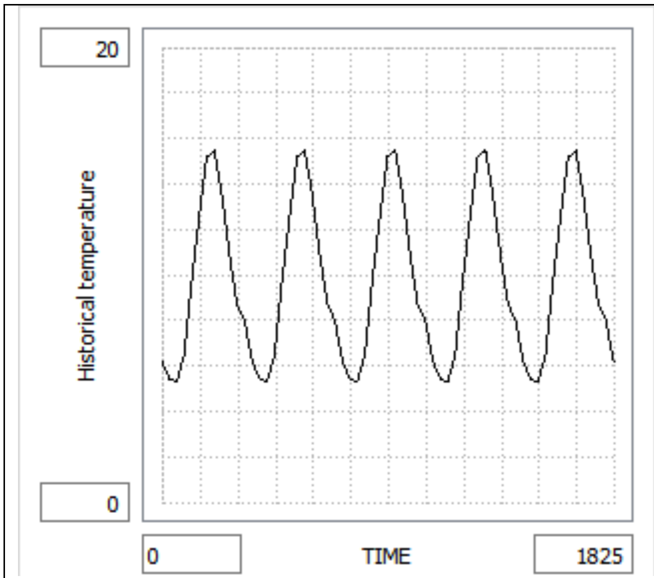


Figure 12: Historical temperature data for Sognesjøen, Ytre Sogn as programmed in Stella Architect

Temperaturprofiler

Middeltemp	jan	feb	mar	apr	mai	jun	jul	aug	sep	okt	nov	des	årsmiddel
Indre Utsira, Rogaland	7.8	6.3	5.7	5.8	8.9	11.0	12.7	16.2	14.6	13.6	11.4	9.8	10.3
Sognesjøen, Ytre Sogn	6.2	5.4	5.3	6.5	9.7	12.6	15.2	15.5	13.5	10.9	8.7	8.0	9.8
Eggum, Lofoten	5.5	5.5	5.5	5.5	6.0	8.0	10.0	12.0	11.5	10.0	10.0	7.5	8.1
Ingøy, Måsøy, Finnmark	5.7	5.0	5.3	5.4	5.4	7.0	9.0	9.2	9.8	8.9	8.0	7.4	7.2

Figure 13: Historical temperature data for Sognesjøen, Ytre Sogn in its original form

Sea and Slaughter Sector

Smolt move from room three in the Juvenile Growth Sector into the Sea and Slaughter Sector through the flow "to sea". Osland Havbruk's smolt producing facility provides the fish for four locations in the Sognefjord – Torvund, Sørevik, Mjølsvik, and Måren. Two locations are where they put the smolt to sea in the spring, and two where they put the smolt to sea in the autumn.

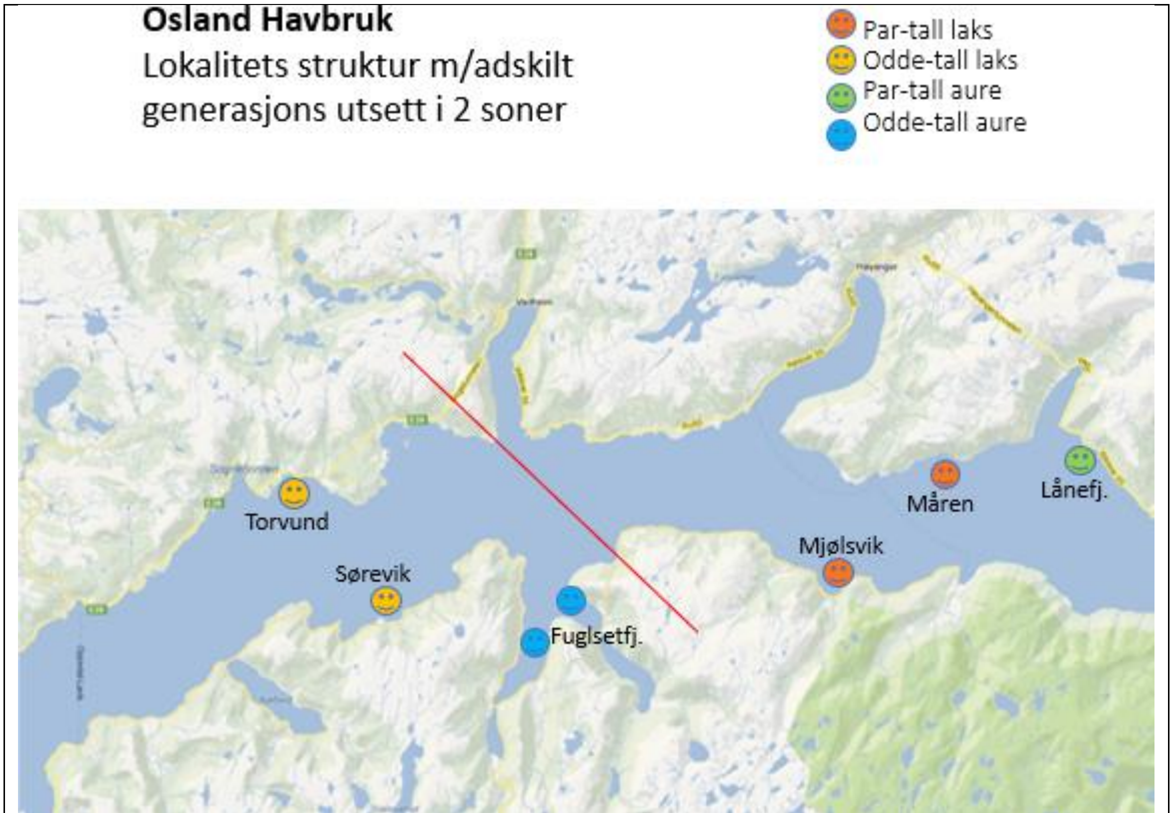


Figure 14: Osland Aquaculture Location structure with separate generations set in two zones. Red is even-number (years) salmon, yellow is odd-number (years) salmon. Green and blue are trout locations. Image provided by Osland Havbruk.

The smolt from one cohort move all at once to a location. In order to move smolt to a location, conditions must be met:

1. There must be smolt in room 3

2. The smolt must be the desired size

3. The location must be empty, and

4. The locations must have been fallowed (empty) for 60 days.

The equation to move the smolt to the locations through the "to sea" flow ensure these four requirements are met. The equation is below:

To Sea[n,n] = IF Parr weight[n] >= Desired Smolt weight[n] AND Locations[n] < 100

AND TIME > Next introduction Date[n] THEN PULSE (MAX (0, Room 3 100g to 500g[n]-Death Rate Room 3[n]*DT),Time when fish are in room 3[n], 0) ELSE 0

Below is an overview of the Sea and Slaughter Sector, including its connection to room 3 of the Juvenile Growth Sector via the "to sea" flow:

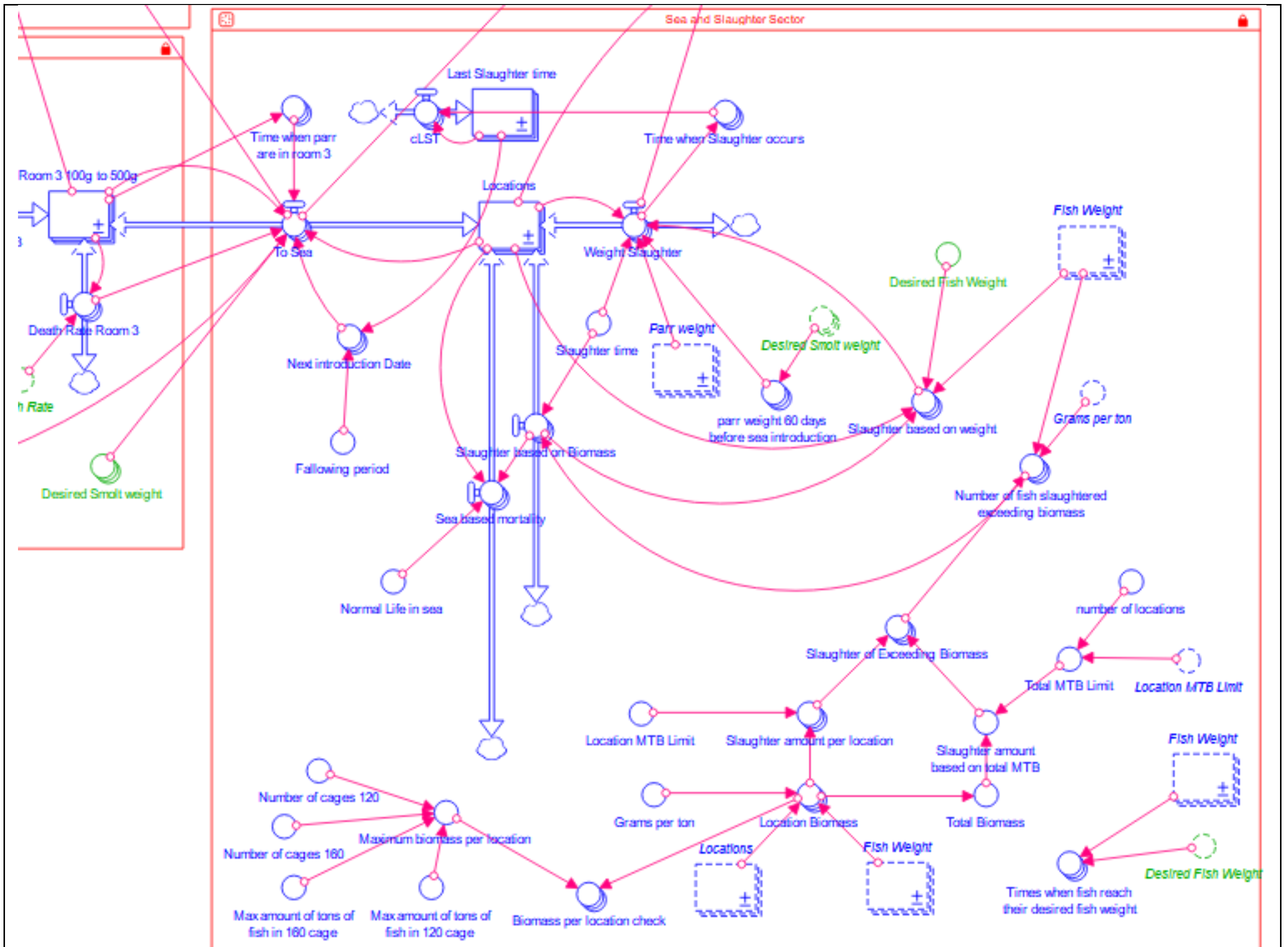


Figure 15: Sea and Slaughter Sector, with the connection of the Juvenile Growth Sector.

Once in the locations stock, the fish grow until they are slaughtered. The ghost variable "fish weight", taken from the fish growth sector, measures the size of the fish. Slaughter happens if any of these conditions are met:

1. When the fish have reached their "desired fish weight".

2. When smolt in room 3 are 60 days away from being ready for sea and the location

needs to be emptied.

3. When the location reaches a certain biomass.

Each of these policies will be explained individually below.

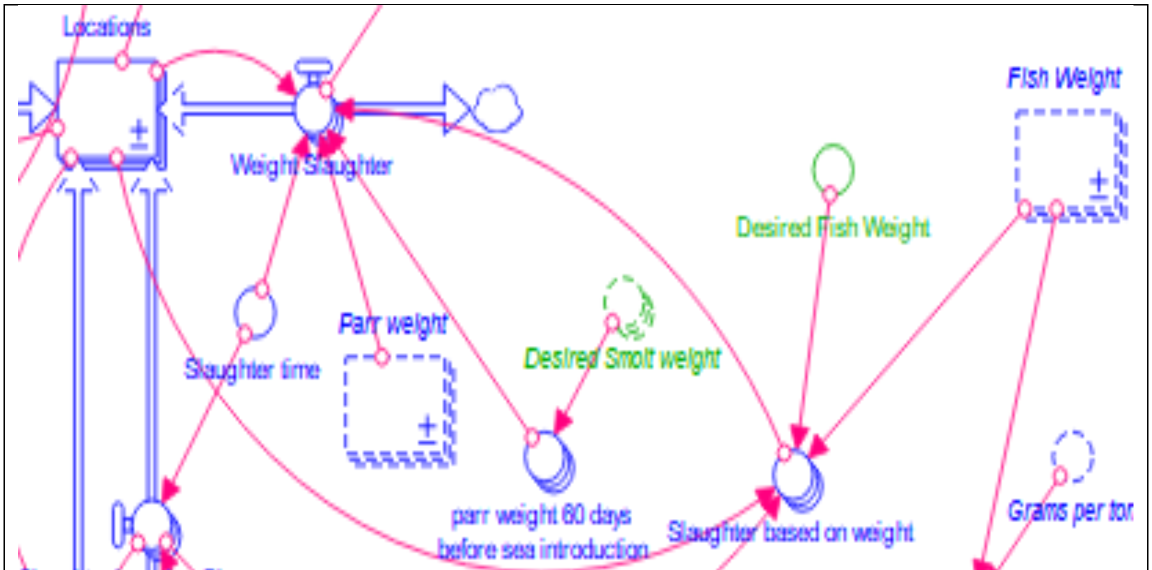


Figure 16: Section of the Sea and Slaughter Sector focusing on the slaughter mechanisms based on fish, parr and smolt weight

Policy 1: When the fish have reached a desired fish weight

The variable "Slaughter based weight" compares a "desired fish weight" to the current "fish weight", with a condition that there must be fish in the locations in order to compare these two. If the "fish weight" is equal to or greater than the "desired fish weight", then the model slaughters everything that is in the location, minus any "slaughter based on biomass" that may have occurred at the same time.

Policy 2: When smolt in room 3 are 60 days away from being ready and the location needs to be emptied.

A location needs to be fallowed (empty) for at least 60 days before a new cohort of smolt can be introduced (Bruland, 2016). As the amount of time it takes to grow smolt to a given size is fixed, it is possible to calculate what size the smolt will be 60 days before they need to be in the sea, and empty the location at that time. This prevents a "backup" of smolt stuck in room 3 if the fish in a location have not reached the desired fish weight by the time the next cohort is ready to use that location.

Policy 1 and 2 are combined in the outflow "weight slaughter". If either condition is met, the fish from a location are slaughtered. The equation is below:

Weight slaughter[n] = IF Parr weight[n] >= Parr weight 60 days before sea introduction[n] AND Locations[n] > 10 THEN Locations[n]/Slaughter time ELSE Slaughter based on weight[n]/Slaughter time

Policy 3: When the location reaches a certain biomass

The group of converters in the bottom right corner calculate when to slaughter based on exceeding the biomass limit. The converter "location biomass" multiplies the amount of fish in each location of the "locations" stock by the "fish weight" at that location. The "location biomass" is then used to calculate the "total biomass", which is the sum of the biomasses at all four locations. The "location biomass" also calculates the "slaughter amount per location", which is each location's biomass, minus the location MTB limit of 780 tons (Osland, 2018). This is the total amount of tons of fish slaughtered per location, which is then added to "slaughter amount based on total MTB" in the converter "slaughter of exceeding biomass". To convert "slaughter of exceeding biomass" to a number of fish, it is divided by the "fish weight" stock. This number is then put into the outflow "slaughtered based on biomass", which takes this number of fish out of the respective locations in the locations stock. This biomass slaughtering mechanism keeps the biomass below the maximum total biomass allowed by law, and provides a more constant flow of slaughtered fish for the farmer to sell.

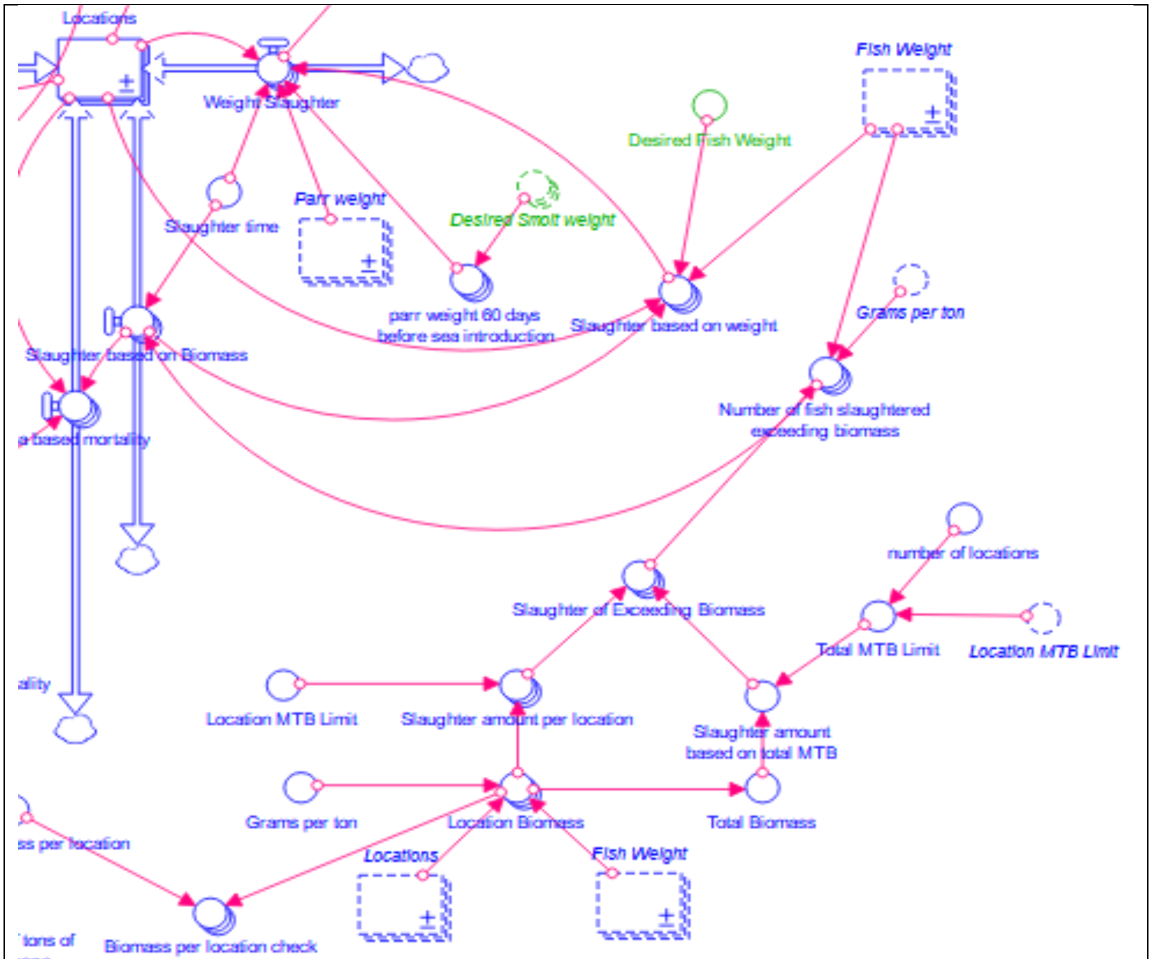


Figure 17: Section of the Sea and Slaughter Sector focusing on the slaughter mechanisms based on biomass

Once the fish have been slaughtered, the location needs to be fallowed for a minimum of two months (60 days) before a new cohort of smolt can be introduced (Bruland , 2016). The converter "time when slaughter occurs" records the slaughter time, and the flow "cLST" (cumulation last slaughter time) accumulates the slaughter time in the stock "Last Slaughter time". The fallowing period of 60 days is then added to the converter "next introduction date" and is part of the pulse function, which allows the smolt from the "to sea" stock to move into the locations stock.

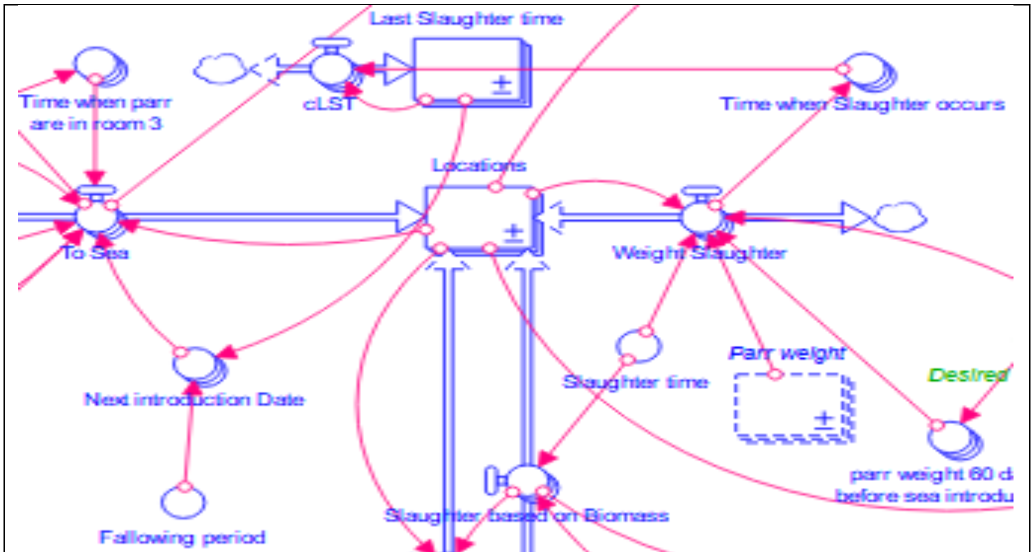


Figure 18: Section of the sector showing the Last Slaughter time, fallowing period, and next introduction date

Our locations stock also has a death outflow, "sea base mortality". This is based on the "normal life in sea", which is the amount of time a salmon spends in the sea (400 days) and the "effect of treatments on mortality".

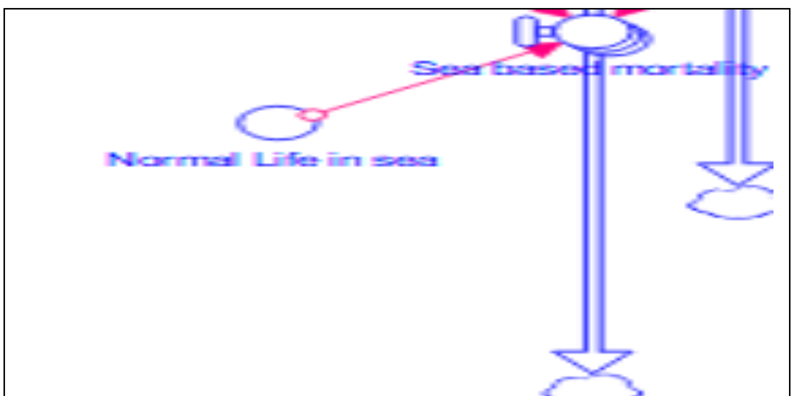


Figure 19: Sea based mortality outflow from locations stock

There is also a biomass per location check in the lower left corner of the sector. This check ensures that the density of the number of fish in any location does not exceed the maximum

number of fish allowed per cubic meter of water in the cages. Osland Havbruk has two sizes of cages, with circumferences of either 120 metres or 160 metres, and a volume of 15278 metres cubed or 27190 metres cubed, respectively. The reference mode uses 6 cages with a circumference of 120 metres. The biomass per location check compares the "location biomass" with the "maximum allowed biomass per location", based on the size and number of cages. The density allowed by the Norwegian government is 25kg of fish per cubed meter of water (Bruland , 2016). If the biomass locations check registers 1, then the locations have exceeded maximum allowed biomass. Using the values from the reference mode, the biomass check never registers that the model has exceeded the allowed density limit.

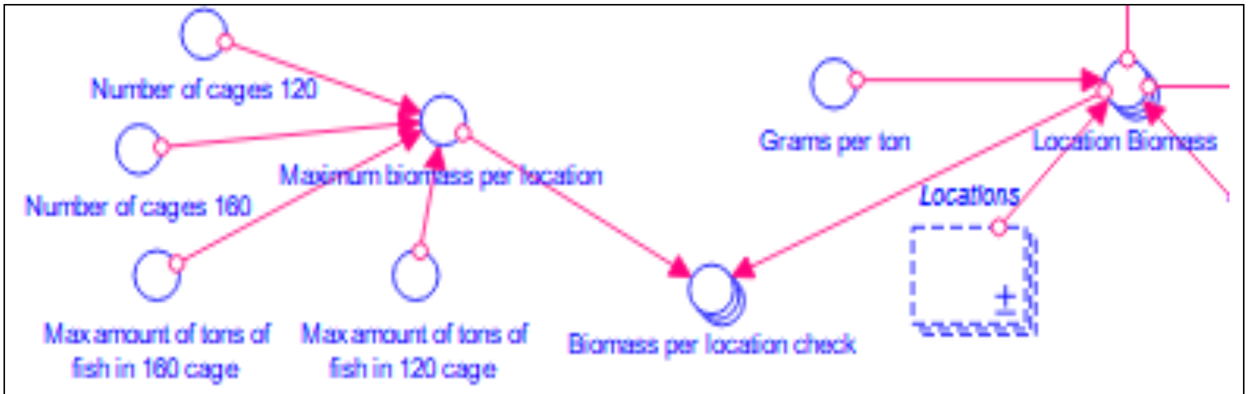


Figure 20: Section of the sector showing the biomass per location check

Reference mode behavioral results

The tables below list the initial values and units of the fixed parameters in these four sectors of the model under reference mode conditions. All of the stocks in the model are initiated at 0 under reference mode conditions.

Table 1: Juvenile Growth Sector Parameters

Juvenile Growth Sector		
Parameter Name	**Value**	**Unit**
First Hatching	0	Days
Second Hatching	10	Days
Third Hatching	192	Days

Fourth Hatching	200	Days
Time to Next Hatching	490	Days
Lifespan	60000	Days

Table 2: Juvenile Feeding Sector Parameters

Juvenile Feeding Sector		
Parameter Name	**Value**	**Unit**
Initial Fry Weight	0.2	Grams
Temperature Parr	14	Degrees c
Feed Conversion Ratio	1.15	Unitless
Desired Smolt Weight	250	Grams

Table 3: Fish Feeding Sector Parameters

Fish Feeding Sector		
Parameter Name	**Value**	**Unit**
Feed Conversation Ratio Fish	1.15	Unitless

Table 4: Sea and Slaughter Sector Parameters

Juvenile Growth Sector		
Parameter Name	**Value**	**Unit**
Fallowing Period	60	Days
Slaughter Time	2	Days
Desired Fish Weight	4.5	Kilograms
Normal Life in Sea	400	Days
Number of Cages 120	6	Cages

Number of Cages 160	0	Cages
Maximum Number of Tons of Fish in 120 Cages	381.9719	Tons per cage
Maximum Number of Tons of Fish in 160 Cages	679.750	Tons per cage
Location MTB Limit	780	Tons
Number of Locations	4	Locations

Juvenile Feeding Sector

The key stock in the Juvenile Feeding Sector is the "parr weight".

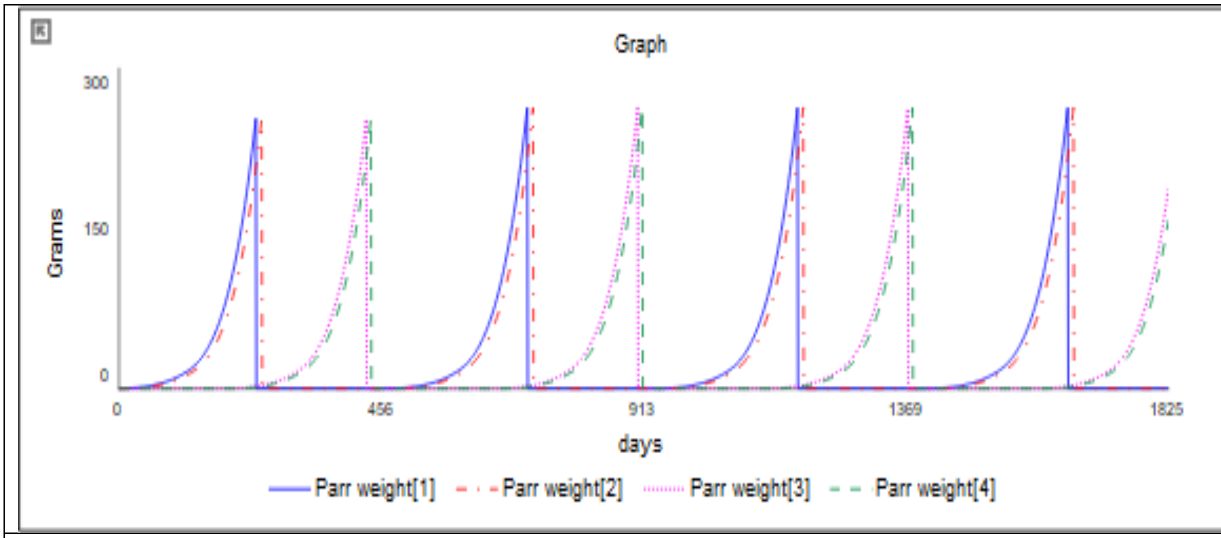


Figure 21: Reference mode parr weight growth, all four cohorts

Within each cohort the graph exhibits a regular pattern as temperature is fixed and there are no lice in the Juvenile Growth Sector. Each cohort of parr grows to the "desired smolt weight", and then the model resets the weight when that cohort has moved out of the Juvenile Growth Sector and gone into the Sea and Slaughter Sector. Cohorts 1 and 2, and cohorts 3 and 4 grow at the same time.

Juvenile Growth Sector

The key indicators in the Juvenile Growth Sector are the graphs of the time spent in each of the four rooms. In the reference mode, the amount of fish and the time spent the four rooms looks as below:

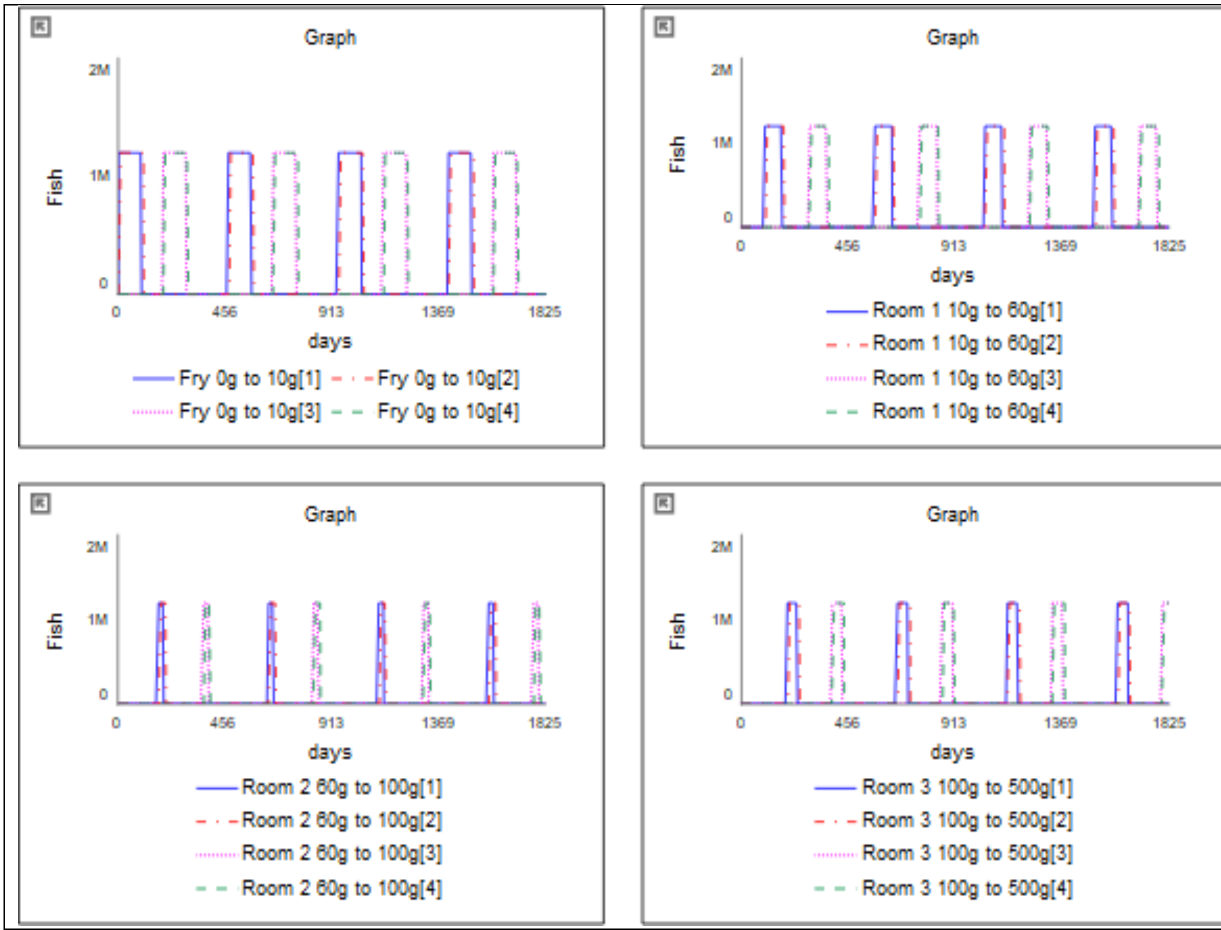


Figure 22: Graphs, number of fish and time spent in the four rooms in the juvenile production facility

As the amount the parr grow in each room is different, the amount of time spent in each room is different. Though not apparent in the graphs, due to large amount of fish, the number of fish in each room does decline slightly due to the death rate of 20 fish/day. As four different cohorts are introduced at two different times of year, cohorts 1 and 2 (blue and pink) and cohorts 3 and 4 (red and green) are in the rooms at the same time.

Fish Feeding Sector

Much like the Juvenile Feeding Sector, the key indicator is "fish weight" growth.

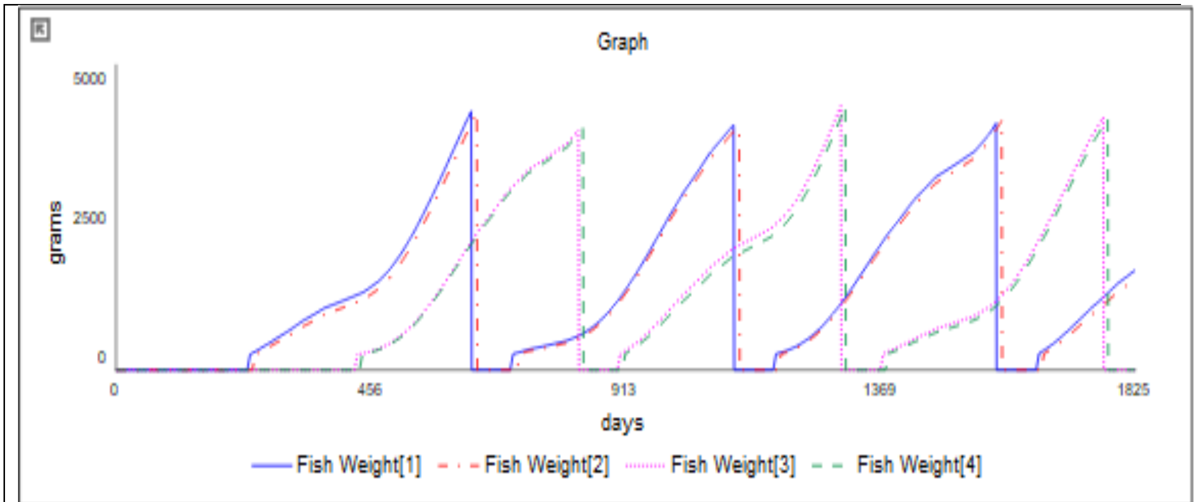


Figure 23: Fish weight growth, without the effect of lice

This graph is a bit less normal than the graph for "parr weight", due to the fluctuating sea temperatures slowing and speeding up feeding. The fish weight resets itself to 0 after the cohort has been slaughtered. In the above graph, the effect of the lice sector has been turned off, to reflect what growth would look like under ideal health conditions.

The fish also do not always reach 4.5kg, as there is a policy where if the next cohort will be ready to use a location 60 days in the future (the minimum fallowing time of a location allowed by law), the fish in the location are then slaughtered in order to free space for the next cohort.

Sea and Slaughter Sector

The most important indicator in the Sea and Slaughter Sector is the biomass versus the maximum total biomass (MTB). That is to say, the biomass of the four locations in the fjord versus the maximum amount of biomass in four locations allowed under law. The graph of biomass vs. MTB is below.

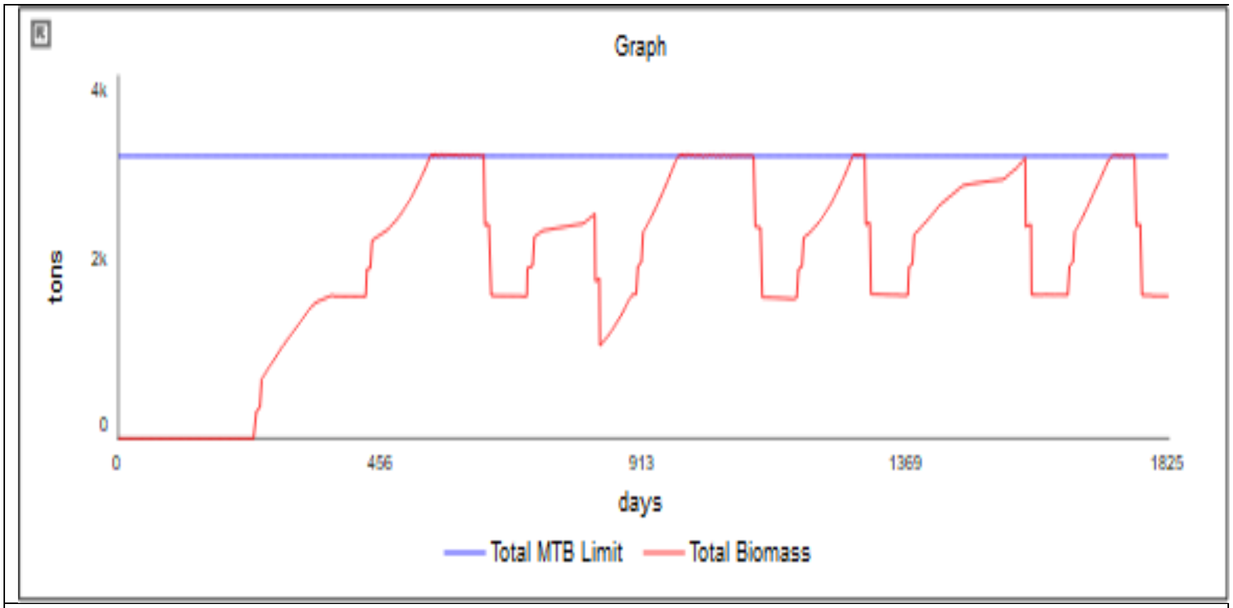


Figure 24: Maximum total biomass limit vs total biomass

The goal of the fish farmer is to be as close to this maximum as possible at all times. In the reference mode, from the time the first cohort goes into sea until the end of the simulation, the average total biomass is around 61% of the maximum total biomass.

Lice Model Description

One of the dominant problems farmers are combatting in terms of disease breakouts is salmon louse, a fastest growing parasite found on Atlantic salmon. Outbreaks of the parasite are enduring as a consequence of intensive fish farming. The larvae released from infected fish moves over the large coastal areas with water current and spread between farms (Samsing, Johnsen , Dempster, & Oppedal, 2017), as far as 100 km from the source of the original outbreak (Thorstad, 2017). Therefore, strict regulatory production restrictions, have led to nearly a full stop in grants of new sea-based production licenses in Norway (Bjørndal & Tusvik, 2016). Hence, this problem can be treated with different solutions, such as chemical treatments of affected fish or use of lice eating fish. But that elevates the production costs significantly; eventually customer pays for that at the end. Sometimes the legal authority can demand slaughtering the entire stock, if the outbreaks are too severe (Norwegian Ministry of Trade, 2014; Bennich, 2015). If that happens, a fish farm can be wrecked financially.

When it comes to fish escaping, a monitoring program has introduced since 1988 to keep a record for the escaped fish from the sites (Bennich, 2015). Every year, since then, the number of escapes has observed always been above the recommended levels (NASCO, 2008). These escapes are interbreeding with the wild population and damaging genetic diversity and productivity. Perhaps, escaping farmed salmon poses a significant threat to the wild populations (McGinnity, 2003).

As fish health is a prime concern and complex problem for the fish farms, an explicit sea lice sector is modeled by *Richard Hesleskaug* and integrated with the production model to understand the dynamics.

The following chapter is taken from the paper **"Modelling the Impact of Coordinated Policies to Reduce Sea Lice Abundance in Farmed Salmon Populations"** (Hesleskaug , 2018) to understand the lice lifecycle and effects on salmon production and economics.

Sea based period and outputs concerning the lice model

When cohorts are put into sea-based locations, there is a change in the dimension of the array values from cohorts to locations. Even though these are still separated by cohort in the different locations, it is necessary to monitor the biomass in what is essentially different stages of the same process. If smolt are introduced at different times of year, they should be different weights at the time of introduction in order to continually maintain as close a biomass as possible to the maximum allowed biomass (MAB). This is because fish grow more slowly at lower temperatures, and because of desired weekly slaughter due to starting costs of processing (Osland, 2018).

As an output to the lice model, the structure separates the locations in a matrix with infection pressure as a function of host population and seaway distance as input variables. As these relationships change over time and with seasons; it is likely that the order in which you put fish

into the four different locations and the time of introduction to these locations has an impact on how lice will infect these locations and continue reproduction.

The model uses the number of fish in locations along with lice estimates and their dispersed infectivity over seaway distance between locations in order to initiate treatments. This dispersal is a point of own estimations, as this is usually determined by physical counts on sampled fish, and there is not sufficient research that empirically states the population of younger stages of lice based on counts of adult and pre-adult lice. The equations used for estimating the between- location infestation pressure are described in detail in the lice model description. However, such calculations are highly dependent on lice mortality rate, which in this case is both mortality of the attached stages of lice and early stage lice that are unable to find a host within viable time. The estimated attachment rate is therefore based on an approach that can be tested against the production in each location separately, with the estimates of external pressure added. Over time, this generates the effect that as long as one of the locations holds reproductive lice, other locations with hosts will get infected without any larvae originally produced at that location, making external infection pressure especially important at early sea-based stages (Aldrin, Huseby, Stien, Grøntvedt, Viljugrein, & Jansen , 2017).

The policy model connected to the lice sector initiates treatments for high lice counts, and this module has an effect on the feeding of sea-based fish. Even though the effects of different kinds of treatments on fish may be specified, and these in reality have different impacts on the feeding and mortality of fish, the model returns the expected negative impact on fish growth in the form of stopping the feeding of fish for some days before treatment, which in turn temporarily stops the weight growth, delaying the growth towards desired weight while mortality remains constant, giving a lower count of fish than without treatment when they reach their target weight.

In addition to chemotherapeutic treatments, the policy model contains a cleaner fish sub-model, that releases cleaner fish into the salmon locations, increasing the mortality rate of pre-adult and adult stage lice through an effect on mortality multiplied with the fraction of cleaner fish of hosts. This stock is refilled when initiated by the user, and is emptied through a constant mortality rate (Aldrin et al 2017).

Lice life cycle

The salmon lice are directly transmitted parasites, which have a planktonic phase and a parasitic phase in their life cycle, without the need for an intermediate host before the latter phase (Krkosek, Morton, Volpe, & Lewis, 2009). The copepodid is the infectious stage when the louse attaches to a host and develop through chalimus and mobile stages of its life cycle. These latter stages include the louse`s reproductive stages from which non-feeding nauplii hatch into the water column. These may drift for several days before developing into infectious copepodites, and the duration of these phases vary with water temperature (Stien, Bjørn, Heuch, & Elston, 2005). An overview of the model structure is shown in Figure 25:

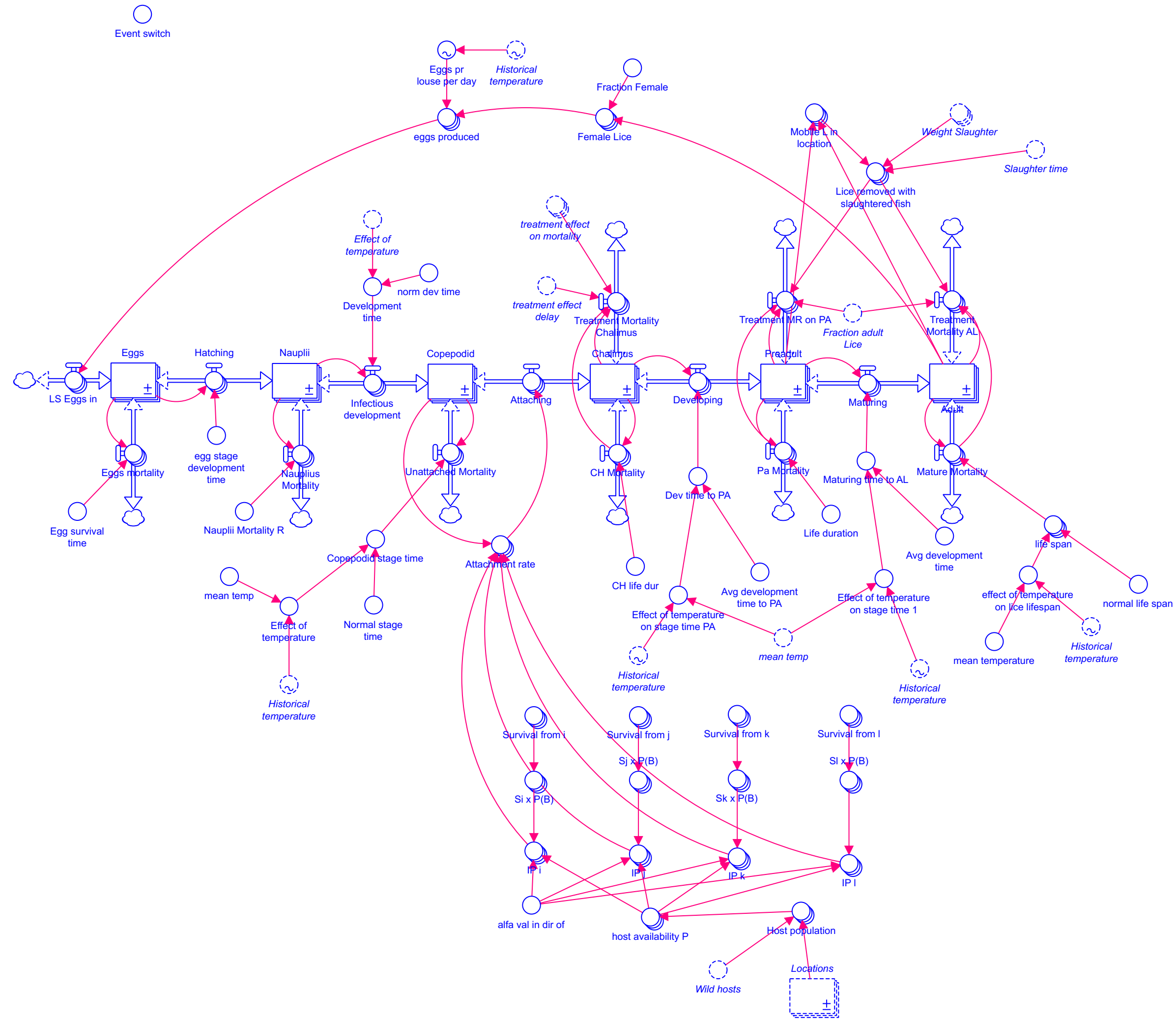


Figure 25: Overview of the lice population growth and infection pressure structure. The aging chain simulates the population in the distinct stages of lice development, while the infection structure in the lower right corner calculates infection pressure between locations.

The change through these phases changes the size and behavior of the lice, as they transition from being sedentary on hosts to being freely mobile on its host and motile among hosts (Krkosek et al 2009). The abundance of lice and their development is seasonal, affected by temperatures during the duration of development stages.

The spread of Lice abundance

Lice infestation is driven endogenously at the farm level by a reproduction process and dependent on the availability of hosts, temperature and salinity (Stien et al 2005). At the regional level the inter-farm dispersal of lice has been shown to depend on seaway distance from neighboring farms hosting infectious lice (Kristoffersen, Jimenez, Viljugrein, Grøntvedt, Stien, & Jansen, 2014). Biomass as an expression for host availability, distance between locations and temperature act as reinforcing factors in this model, while the weighted effects of other factors, such as salinity and daylight hours are less thoroughly documented on farm and regional scale, and are therefore excluded from the model framework. In the model, farmed biomass is treated as an endogenous variable, while temperature is based on historical data, as is the migration pattern and population of wild salmon as an external variable of hosts that would sustain a population of lice even if the farmer in question fallowed all his locations at once. Damage to the wild population from high infestation levels is not studied within the model framework, although such infection is known to harm young stages of wild salmon, and over time contribute to the reduction seen in the total return of wild salmon (Krkosek et al 2009).

Below are the data based (Figure 27) and model generated lice counts (Figure 28) as a reference mode to the problem. The real-life system operates with treatments and cleaner fish as regulated, making the reference mode generated by the model one where policies are turned on, as opposed to how models are usually initiated. In addition, the lice model is initiated with fish in locations 3 and 4 to utilize the 5-year simulation on lice abundance.

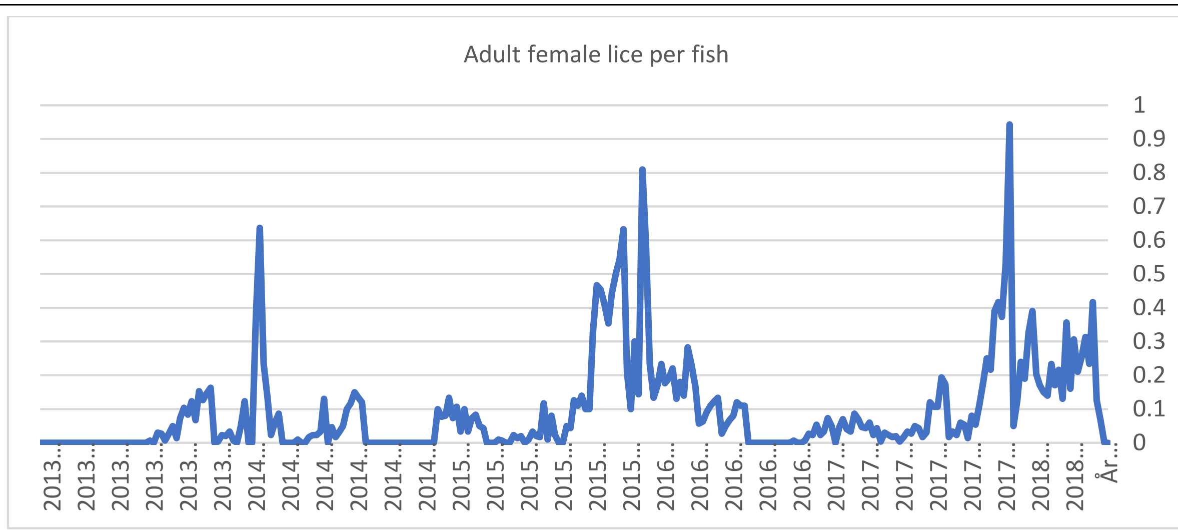


Figure 26:*The average count of adult female lice per fish in three locations (Sørevik, Torvund and Måren)*

2013 – 2018. Mjølsvik was left out of the dataset due to incomplete data to remove biased results in the graph.

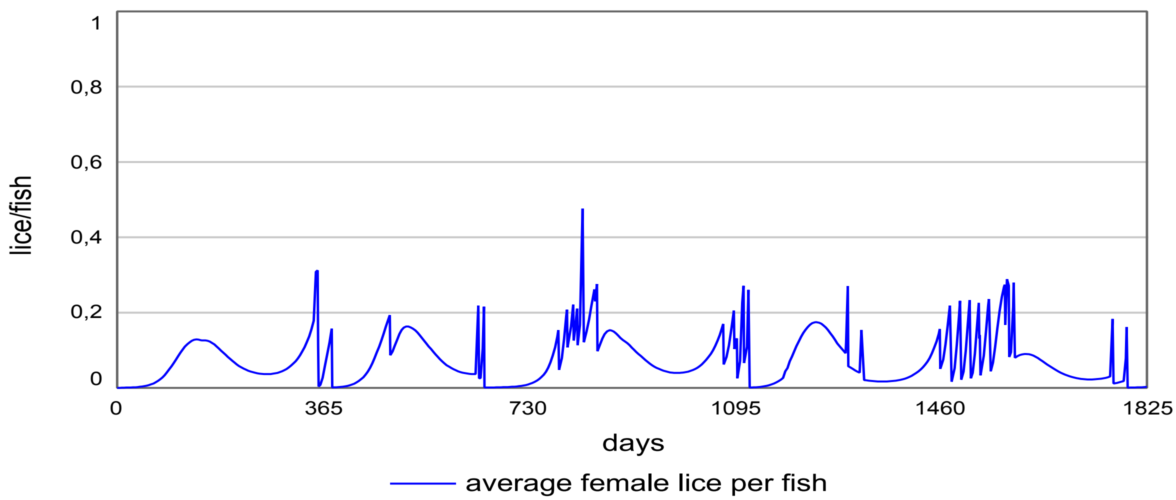


Figure 27: Model generated lice abundance (5 yrs) of all attached stages of lice on all four modelled locations, showing comparable data to the reference mode (Figure 26)

In the model the focus is on the four locations operated by Osland containing salmon; Torvund, Mjølsvik, Sørevik and Måren, excluding locations run by other operators in the area. This is a simplification chosen to focus the model on what the farmer can do to influence his surroundings without having to consult with other producers nearby. This is, however, not difficult to expand in a later version of the model in order to adapt to several operators. The focus on salmon is also a simplification, as the rainbow trout licenses operated by Osland are close by and susceptible to parasite emission to and from its neighbors even if these are different species. *Lepeophteirus salmonis* is a specialist on Salmon species, and will therefore also affect trout populations. While some generalist lice exist, these are not a problem on the same scale as salmon lice on salmon population (*Caligus elongatus*) (Jansen, Kristoffersen, Viljugrein, Jimenez, Aldrin, & Stien, 2012).

Lice infestation may be transferred by two main modes of transportation. Local transmission from hydrodynamic movement from farming and long-range transmission caused by wild migrating fish (Werkman, Green, Murray, & Turnbull, 2011). In the model, the focus is on transmission through water column dispersal, as the latter mode of parasite transfer mainly affects the migrating wild population of salmon. The sea water temperature affects how far inter-location connections reach, as well as development times between stages and mortality rate.

The model uses survivability of the infectious stage over distance as a proxy for diffusion of planktonic stages of lice. This has been applied to earlier models (Kristoffersen et al 2018). This approximation lets the model calculate generic simulation results that are independent of wind and currents, but that still hold explanatory power in the model.

There are four important inputs to the sub-model: 1: The farmed fish population simulated in the production sector. 2: The wild fish population, varying through seasons. 3: The historical temperature. 4. The slaughter of fish in locations.

The assumption made by Kristoffersen et al (2014) is used in the model. He assumes that exposure to salmon lice infection depends on the number of infective copepodites, that is, the stage of lice that are able to attach to hosts, in the local environment. Further, the model takes use of some of the same data categories: Numbers of fish, female lice, water temperature. In addition, the model contains a full life cycle model of the lice development, that helps estimate the production of life stages within locations, as well as those locations` impact on other locations` external infection pressure.

This is matched with data on Pre-Adult and Adult Male (PAAM) counts, which is also mentioned in Kristoffersen et al (2014), because the physical counting of smaller stage lice is difficult, creating biased data that does not fully represent the lice abundance. One can therefore estimate their numbers backwards by applying known mortality rates and development rates determinant in their move through the population growth structure.

Lice population growth and life cycle

At the center of the lice module are the location population stocks (Figure 29), which accumulate the net flow between lice births and lice deaths in each location, shown as one structure with arrayed variables. Each array dimension represents one of the locations in the producer’s network. This lets the model simulate internal reproduction of lice in each of those locations. One could theoretically model the total infestation in the area with one aging chain, but that would imply perfect mixing of all lice development stages over the production area. This would make it impossible for the producer to simulate the impact of taking different managerial actions on different locations on the lice abundance.

The sector is therefore divided, following the cohorts of fish released into the sea stage of their development in the production model. This leaves the lice in infective stages that are “in transit” between locations belonging to their original location until they attach to fish in another, even if these physically are somewhere between the two. This helps determine the directional pressure connecting two locations by reducing the number of stocks involved in the structure.

The life cycle of the salmon lice is broken down into the developmental stages that are most important to the abundance calculations: eggs, larvae (nauplii), copepodites, chalimus, pre-adult and mature lice. The last stage is divided between male and female lice at a fraction of 0,5.

Eggs are released from pairs of egg strings on the gravid female lice. Each string contains around 150 eggs on average (Stien et al 2005), increasing from the first set to recorded fifth pair of egg strings produced by a female louse.

Eggs hatch and nauplii are released into the water column, and develop into their next larvae stage depending on water temperature. The inflow of eggs is regulated by one reinforcing and one balancing loop that says that the more available hosts there are, the more lice will be able to find one and reproduce, to increase the number of eggs produced in the next generation.

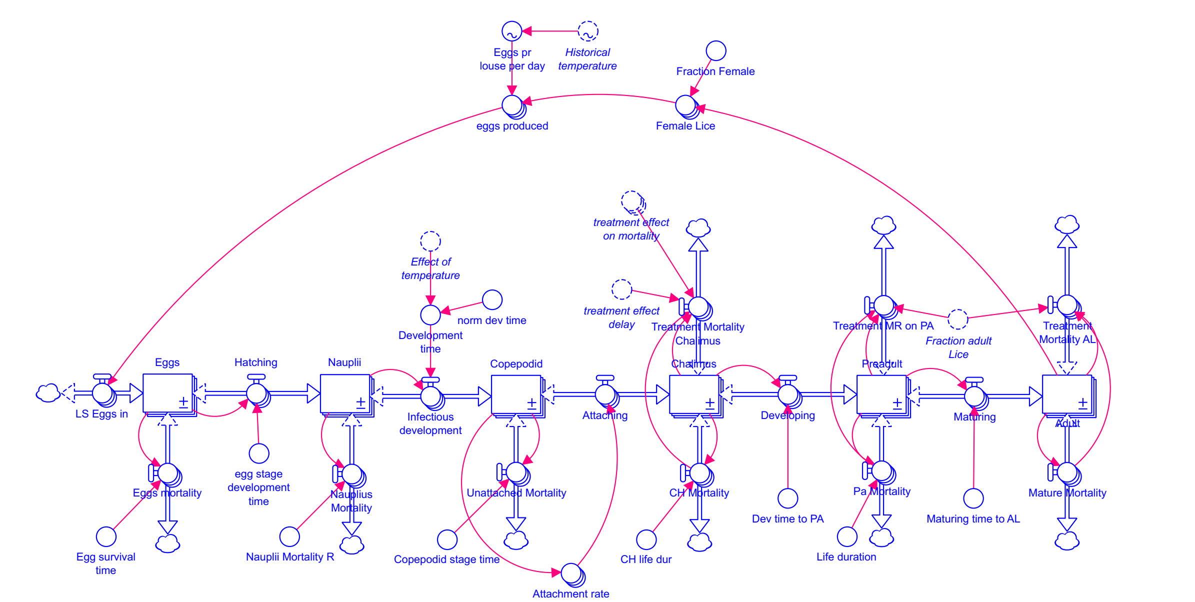


Figure 28: The structure of the lice aging chain and reproduction divided by populations of each stage of the lice life cycle.

Water temperature is an important part of development time in all life stages of the salmon louse, and is therefore built in as a historic variable that recreates five years (2012 – 2017) of temperature data in the region. Research on the differences along the Norwegian coast on this dependency indicates lower lice abundance in northern, colder areas, and higher abundance in southern production areas, but this could also be linked to lower biomass and densities of hosts (Jansen et al 2012). Samsing et al (2017) show strong seasonality in lice abundance and inter farm infection pressure, which is likely connected to temperatures. This gives variable development and mortality rates for some stages, given in Table 5

Table 5: Initial parameter values for development and mortality rates in the lice population growth model

Development	Hatching	days	5
(mean)	Infectious development	days	4
	Attaching	1/days	Equation
	Developing	degree/days	15.5
	Maturing	days	11
Mortality	Eggs mortality	days	6
(mean)	Dispersal (Naupli) mortality	1/days	0.17
	Unattached mortality	degree/days	155
	Ch mortality	1/days	0.05
	Mature mortality	1/days	0.047

The present model has a variable that shows the effect of an increase or decrease in temperature on fish and lice populations, but this is not discussed further with regards to the effect on lice abundance in this paper.

Beginning at the earliest stage of the salmon louse development, the eggs develop from egg strings released by an adult female louse. They then hatch from the egg stage at a rate of

Hatching = Eggs / Egg stage development time

with a mortality of

Eggs mortality = Eggs / Egg survival time

The planktonic stages are important mainly in order to calculate the population sizes of the next stages, which later helps calculate the attachment rate of the first infectious stage of lice. There are two outflows from this stock: The development rate flow equation, which is stated as

Infectious development = Nauplius (larvae) / Development time

with development time being temperature dependent, and the mortality of the larvae stock being continuously subject to its mortality rate,

*Nauplius mortality = Nauplius * NL mortality rate*

The next development stage is the copepodid stage, where the population of planktonic lice in the water column become parasitic, and will have to attach to a host in order to continue their

development through the stage structure. This stage-representing stock accumulates all the survivors from the Nauplius stage, and is emptied by a mortality rate and an attachment rate, that is, finding a host, which over time will lead to next stage development. The Copepodid mortality rate is:

Unattached mortality = Copepodites / Copepodid Stage Time

The attachment rate is calculated with the number of copepodids and time, determined by an infection pressure. This structure is separate from the aging chain model structure.

The next paragraphs describe the co-flow of farmed fish populations and the wild population as available hosts and the growth of the lice population between farms with a delay, before returning to the description of the final stages of lice development.

Parasite transmission between locations

Transmission of parasites between locations is a key factor in the population dynamics of sea lice (Aldrin et al 2013), and thus an important part of the real-life system depicted by the model. In system dynamics, there are many former examples of diffusion of disease, like adaptions to SIR- models, but these are generally between humans or within one species, and with the indicating conditions being either infected or not infected. Since the lice transmission is a parasite-host relationship, dependent on the presence of two species as well as being transferrable and reproductive at a larger scale than regular contact rates (infected / not infected) will accurately represent, the model utilizes an array structure to model a four-way diffusion between the locations.

When a single farm lice population was modelled by (Hamza, Rich, & Wheat, 2014), the lice population and the farmed fish mixed randomly, in order to recreate the exponential growth of the parasite population and a policy system to handle single farm infestation. In this scenario, when there are

four locations in a network, it is necessary to build a disaggregate model that fits better with the distance and temperature-dependent infection between the neighboring locations.

Samsing et al (2017) describe a seasonal model-generated variation on the number of connected locations because of a decreased development rate and therefore longer range of the pre-infective stages in low temperatures. This factor is accounted for by changing development times in the model, however, the network modelled contains locations that are all well within this range all year, meaning there are links between the locations within the normal range of temperatures in the region. This variable is however, an interesting way to expand the framework of further research into regional level and among several producers. This is an important topic for research as it greatly affects the effectiveness of separation zones and production areas.

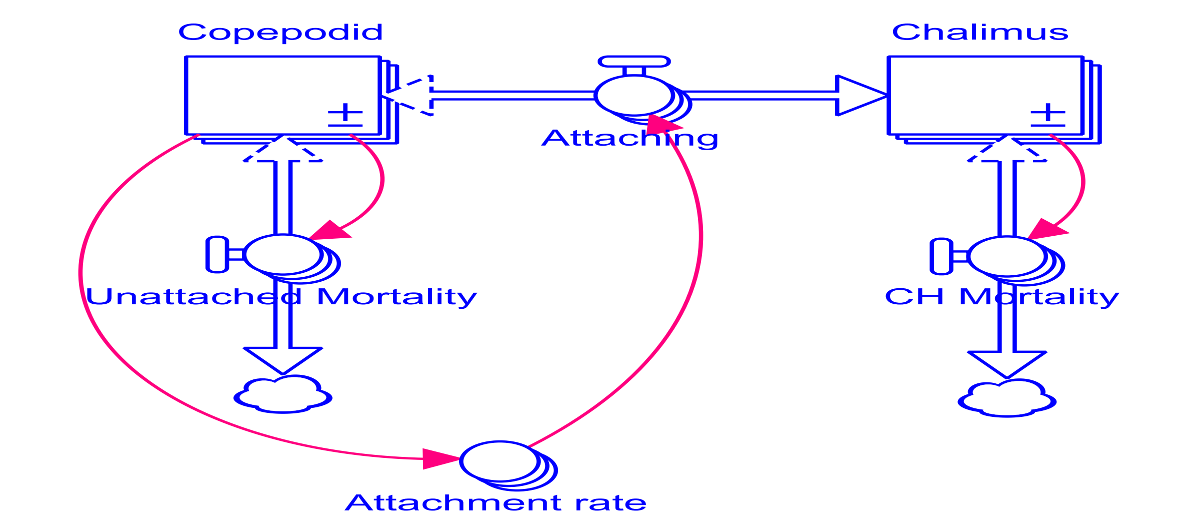


Figure 29: Model section highlighting the flow between stages and the connection of infection pressure, which gives the attachment rate. This is variable accounts for the step between produced infective lice and lice that find a host and start reproduction.

The internal infection pressure (Figure 30) is defined as the population of infective stages multiplied with transmission rates. As the distance between a location and itself is set to 0, the internal infection pressure is most significant to each location, given that hosts are available, and that there are lice present the previous time step (Aldrin et al, 2013).

The infection rate is a product of the abundance of sea lice, survivability over distance, available hosts and a parameter alpha, given a constant mortality rate. Unattached stages of lice will, at slaughter and fallowing events, still disperse to the surrounding water column, giving a short time where these stages of eggs and lice are present and modelled in the aging chain even if there are no available hosts, but these will not develop past the infective stages in that location.

Some of these pre-infective and infective stage lice will, however, contribute to the infection pressure of the other locations where hosts are available, and to wild hosts.

The external infection pressure is the sum of contributions from all external source farms, relative to the distance between source locations (*j*) and recipient locations (*i*). The relative contribution S*ij* from a source farm (*j*) with seaway distance d*ij* is defined by the formulation (Aldrin et al (2013):

$$Sij = \frac{e(-1{,}444-(dij\wedge 0{,}57-1)/0{,}57)}{e(-1{,}444-(djj\wedge 0{,}57-1)/0{,}57)}$$

The distances between locations are fed into a matrix (Figure 31) and calculated for each distance relationship connecting Torvund (*i*), Måren(*j*), Mjølsvik (*k*) and Sørevik (*l*). The seaway distance is rounded up to its closest whole kilometer (calculations in appendix).

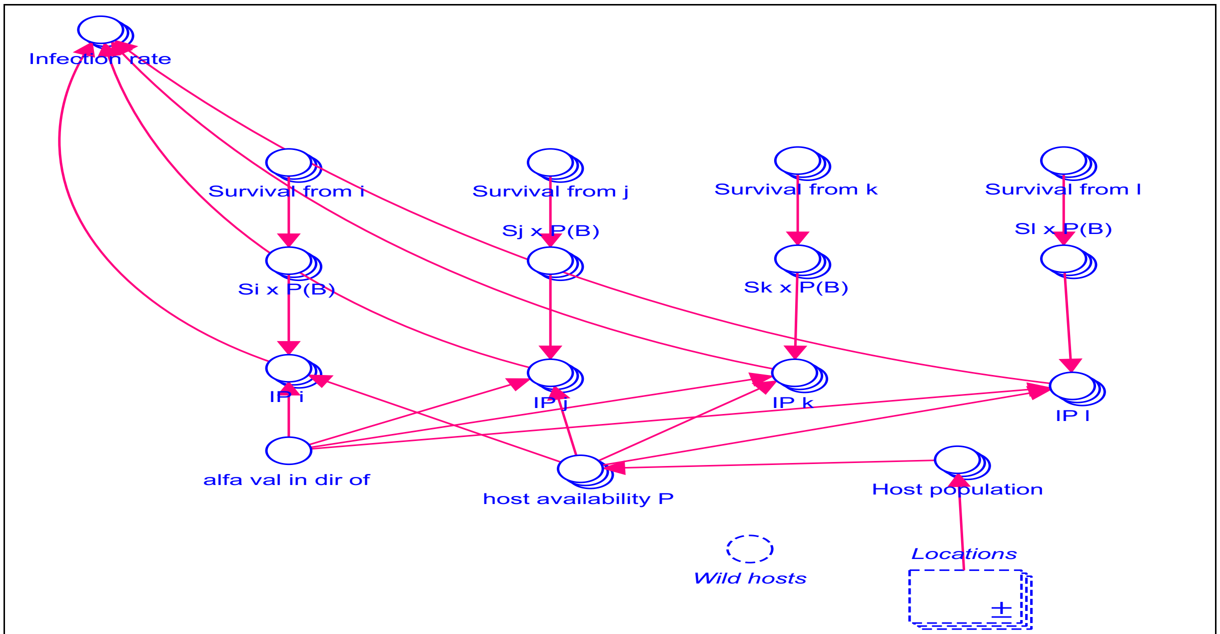


Figure 30: External infection pressure sector, showing the structure used to estimate the infective pressure within and between locations, used for calculating the number of lice that successfully attach to a host from the parasites produced.

When the risk of infection per day is established as parameters in the model, 16 in total, these are multiplied with a parameter, which is a normalized value between 0 and 1. This represents a power variable to the infection that describes the value of the produced parasites that successfully attach and continue their stage development.

This gives the infectivity at a given distance and between locations to indicate one location`s dispersed lice pressure on another location that may be within range and in the direction this dispersal must have in order to reach another location.

This value is multiplied with a probability of there being hosts P(B) in the sector. As actual infection pressure is calculated in the aging structure of the model, this is a binary choice of 0 or 1, dependent on there being fish in the target location at time of dispersal. In Aldrin et al (2013), this condition is stated as fish or no fish. Since it is reasonable to assume that there must be a number of hosts that is significantly different from the wild population for this indicator to be 1, and the model continually calculates the actual number of fish in each location, the number of fish for P(B) = 1 is set to 10 000 fish. This value is then multiplied with the number of copepodid stage lice in the location of origin, to calculate the attachment rate from one location to another.

$AR_{i,j} = S_{i,j} * \alpha_{i,j} * P(B_j) * C_i$

Where C_i is the number of copepod stage lice in location i at that time step.

The external pressure is added to each location`s own production of internal pressure in order to calculate the effect of total infection pressure, meaning that even if only one of the locations were infected in the area, the other three would also become infected given availability of hosts in those locations over time (Duggan, 2016).

This gives total infective pressure for one location i:

$Cii * \alpha ii * Sii * P(Bi) +$

$Cii * \alpha ji * Sji * P(Bi) +$

$Cii * \alpha ki * Ski * P(Bi) +$

$Cii * \alpha li * Sli * P(Bi)$

Which is calculated separately for each of the four locations i, j, k, l.

When lice attach to a host, they move from being planktonic to the parasitic stages, the first being the Chalimus stock of the model, implying the next stage of development. From this stock, there are two outflows describing mortality, the first being life span, in which life duration is estimated at 20 days, matching a mortality rate of 0,05 (Kristoffersen, 2014).

CH mortality = Chalimus / CH Life_duration

The second being the mortality caused by treatments initiated by the farmer:

*Treatment mortality chalimus = Chalimus / (Chalimus*treatment_effect_on_mortality/treatment_effect_delay)-CH_Mortality)*

The next outflow is the development time to the preadult and reproductive stages, where development time is dependent on temperature by having an average development time of 15.5 days multiplied with the effect of temperature on that development time. The effect of temperature is the deviation of the historical temperature from the average temperature of 10 degrees C, giving the effect of temperature through a graphical function:

Effect of temperature = Temperature / average temperature

Which gives the rate of the development into the next stage:

Developing = Chalimus / Dev_time_to_PA

The outflows from the pre-adult and adult stages are the same formulations as for chalimus, with the addition that cleaner fish add to their treatment mortality. This is due to the cleaner fish effect on mortality, which is dependent on size of the parasite.

From pre-adult, the lice mature into their reproductive stage through an inflow from the pre-adult stage:

Maturing = Preadult/Maturing_time_to_AL

In the last stage of development, sea lice reproduce. There is a loop back to the inflow of eggs that starts the development structure. This inflow is calculated by multiplying the mature lice population with the fraction female lice, and multiplying with the average number of eggs produced. The birth rate of lice is given through temperature and the normal reproductive rate of lice at some probability of finding a host. This is simplified in the model; there are male and

female lice, at 50% of each. Female lice produce about 300 eggs released from two strings, which in turn become infective stage copepodid that are brought with currents away from the original location.

From the last stock, there is an outflow of mortality, similar to that of the previous stage, also dependent on temperature. In addition, there is an outflow that separate natural mortality from treatment induced mortality, which is connected to the treatment structure and gives increased mortality from the attached lice stages when treatments are initiated. This outflow is similar to the one in the two preceding stage stocks.

Next, the treatment structure is described. This structure contains variables for calculating the abundance of lice in different stages. Most important is the adult female lice per fish, which is used to initiate treatments. Further, there are switches that let the user choose between policies for reducing the lice abundance.

The treatment structure

Treatments are an important way to limit the growth of lice abundance by removing attached stages of lice from the fish population. The treatment structure calculates the effect of different treatment policies and adds these to the mortality of parasitic lice stages in the lice population growth segment.

The key indicator for initiating treatments is counts of attached stage lice per fish. This is used to make a decision of whether or not to start a treatment, which feeds into a counter of treatments and a policy option of how treatments are to be coordinated. The model structure of the treatment sector is shown in Figure 31.

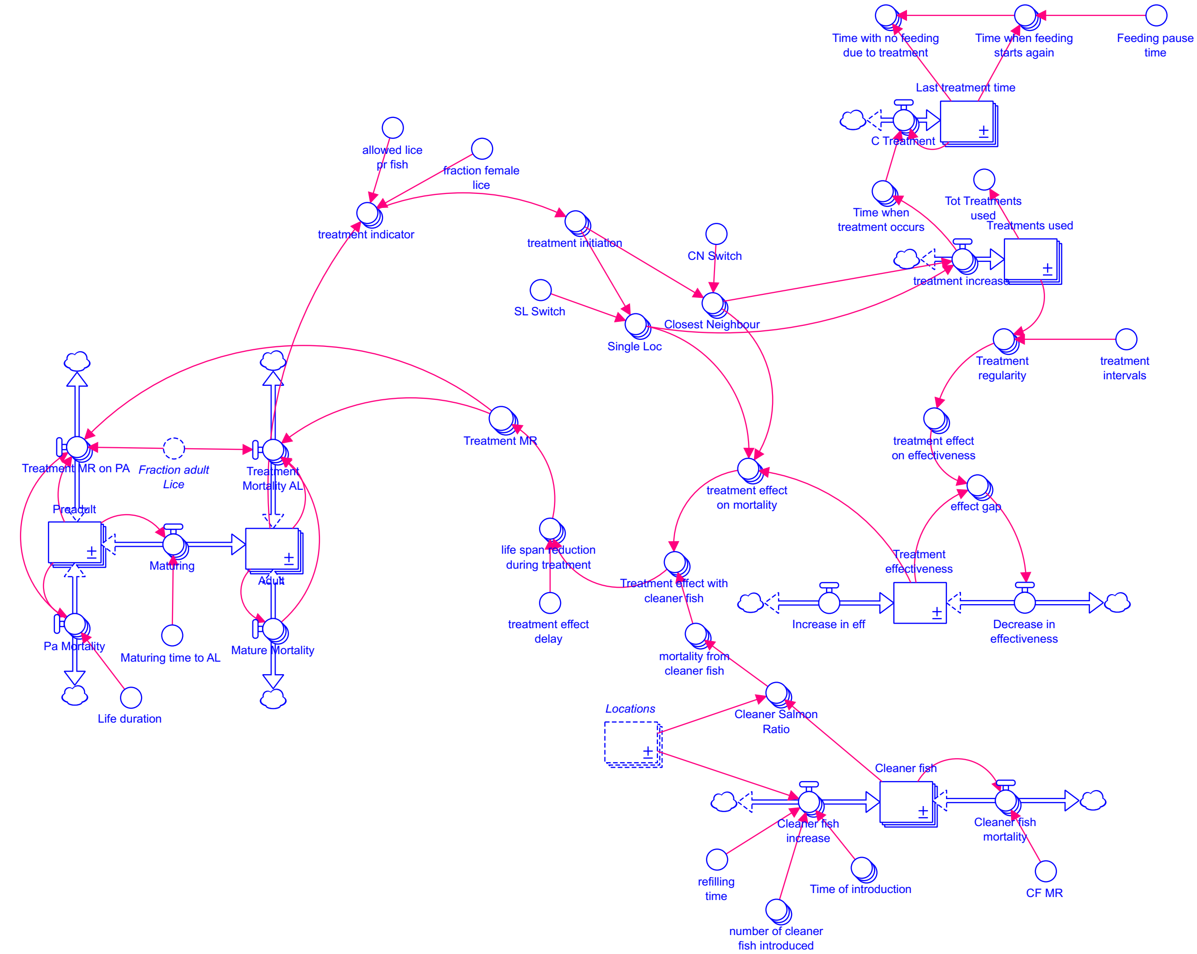


Figure 31: Overview of the treatment model connected to attached stages of lice

Treatments have a negative impact on the average lifetime of lice, meaning that the number of lice that pass through the outflow of lice death increases per DT when treatments are initiated at an endogenously generated “lice per fish” fraction. As infestation falls rapidly, so does the next generation’s reproduction, as it is dependent on the population of mature lice. Lice mortality is also influenced by slaughtering fish, as this physically removes attached stages of lice from the locations.

The treatment sub-model is important to the management of the fish farm as one of the main ways of reducing infestation levels once they occur in sea-based salmon populations (the other includes culling of an entire cohort, which is rarely beneficial to the farmer unless it occurs close to the end of production or at especially beneficial salmon prices (Osland, 2017). This is more relevant as a countermeasure to infectious salmon anemia or other viral diseases that form an immediate epidemic threat to other locations and the wild salmon population.) Treatments are also costly, can be damaging to the fish, and are one of the most important decision points for farmers along with feeding rates when fish are in the sea. The model allows for automated treatments or user-initiated treatments through a testing interface, such as introducing cleaner fish to locations at early stages of lice infection.

As an initial setting the model is run with treatments turned off in order to see the effects of unrestricted lice population growth until it reaches a pre-set carrying capacity per fish. This returns s-shaped growth, but varying with the amount of biomass in the sea, as its level stabilizes close to the maximum lice allowed by all fish in all locations. This would in turn start to increase the mortality of fish, and these would not reach their weight goal within the production time of the model.

When treatments are turned on, the model uses the maximum allowed threshold for female lice per fish (0,5) as the indicator for when to initiate a treatment. This decision starts a treatment cycle that increase the mortality of attached stage lice, hence reducing the reproduction of coming cohorts of lice and eventually the infection pressure of that location on other locations. The automated treatments are programmed in such a way as to initiate treatments in the location that experiences the high counts of adult female lice, without regarding policies of other locations` treatments with growing abundance or locations within the peak area of infection pressure (Samsing et al 2017), and this must therefore be specified if the user wants to initiate coordinated treatments at one or several neighboring locations if there are high counts of reproductive stage lice in one location.

When behavior testing coordinated treatments, there are two different policies built in:

- Synchronized treatments in all locations containing fish if one location approaches the threshold value of female lice.

- Treatment of the closest location to the starting location (the modelled locations are paired together east and west of Osland in the fjord, making two sets of neighbors about 6 km from the other. Between the pairs there is an estimated 21km).

The treatment strategy options could be expanded in order to find combinations of treatment events that minimize the number of treatments while achieving the desired effects, as well as combinations that reduce the diminishing effect of repeated use of certain chemotherapeutic treatments.

There is also a counting structure that follows the number of treatments used in each location. This has two functions:

1. The more chemical treatments are used, the less effective they become, leading to a balancing loop that over time could limit their effect and ultimately slow the industry growth

2: It is a way of showing how costs are related to treatment measures.

The cleaner fish structure (Figure 33) is added to the mortality of attached stage lice in the same way as other treatments, but with a somewhat different behavior. With 10% cleaner fish to salmon ratio, the MR of lice increases to 0,079/days, reducing life from 8,2 to 5,2 days at 10c (especially PA stage lice) (Aldrin et al 2017). Cleaner fish inhabit a stock that is physically in the locations along with salmon. These are introduced as a number chosen by the operator, calculated by the desired fraction of salmon in the location, as this fraction influences the effect of the cleaners. The outflow from the cleaner fish stock is a set mortality rate, meaning that the fraction of cleaner fish to salmon is not constant, giving a variable that changes over time with regards to its effect on lice mortality. The introduction of cleaner fish is controlled by introduction times and the availability of fish in that location, to avoid introducing a lice countermeasure into a location where there is no biomass for parasites to attach to (Aldrin et al 2017).

Inflow: *IF(Locations[1]>1000) THEN PULSE(number_of_cleaner_fish_introduced[1];*

Time_of_introduction; refilling_time) ELSE 0

The amount of cleaner fish and salmon from "locations" are used to calculate the cleaner fish ratio, which determines the mortality on lice from cleaner fish (Aldrin et al 2017):

*1-EXP(-0,0823*Cleaner_Salmon_Ratio[1])*

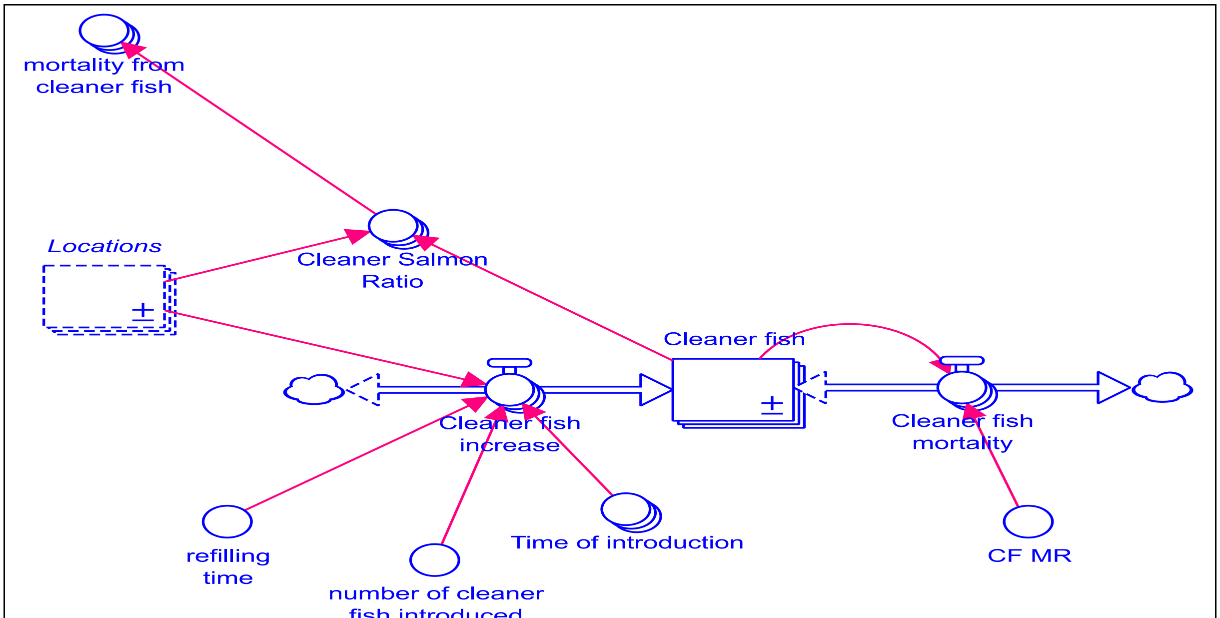


Figure 32: The structure of the cleaner fish model, showing the stock of cleaner fish. the inflow is initiated by the fish farmer, and the outflow has a constant mortality rate of 0,028 (Aldrin et al 2017)

The initial values for the cleaner fish sector are given in Table 6.

Table 6: Initial inputs to the cleaner fish model used with an automatic replenishment of cleaner fish when the population runs low.

Juvenile Growth Sector		
Parameter	**Value**	**Unit**
Cleaner fish (Stock)	0	Fish
Refilling time	50	Days
Number of cleaner fish introduced	10000	Fish

Time of introduction	250	Days
Cleaner Fish MR	0.028	Fish/Days

Economic Model Description

Biomass growth, harvesting decisions and treating diseases are at the core of the operations of any fish farm. To judge the core performance of such a business, among others, numerical values are one of the very important indicators. Management and stakeholders are always considering statistical values as a strong leverage point to visualize a business from different perspective. In addition to that, it enables the stakeholders to understand the complex dynamics of a business and to learn more about that. Keeping that in mind an economic model is integrated to the fish production model. Financial economics indicates how time, information and uncertainty can create incentives or difficulties for a particular decision. Financial economics model is often a very useful tool to test the variables affecting a particular decision.

The primary intent of the economic model is to give a practical illustration of the financial operations of a fish farm. The extended purpose is to find out bottlenecks of the current operation and optimize the profitability by increasing production yield. To do that, standard Financial Statements layout is used. This layout presents relevant formal financial information in a structured manner for different users and purposes. The layout is fairly relevant, understandable, reliable and comparable.

This economic model consists the direct operational costs of the fish farm based on the following assumptions:

1. The plants are fully developed. All fixed costs relating to the plant establishment are disregarded.
2. All workforces here are considered as direct operational costs.
3. Smolt production costs are not calculated explicitly rather a fixed cost per smolt based on their weight classes are accounted.
4. Money is not a limiting constraint with respect to the operations.
5. This model is only taking inputs from the biomass growth and lice sectors but not giving any feedback.

This is a simple yet effective and powerful model to understand the performance of the fish farm. This model is not only calculating all the revenues and costs of a production but also validating the production and treatment model. The model includes the following indicators to measure the performance of the operation.

Revenue

Figure:33 illustrates the revenue stock that accumulates all the income received by the farm for selling produced biomass. It is assumed that whenever the fish are slaughtered they are sold to the current market price based on their net weigh. The total biomass produced, is however, first converted to standardize measurement and in this case "the net biomass weight per Kg". Here the net biomass weight per Kg is 86% of the total weight (Osland, 2018). Five years historic salmon market price (January, 2014- November, 2018) is used based on the weight classes. Historic price developments of salmon are obtained from the NASDAQ Salmon Index (NASDAQ Salmon Index (NQSALMON), 2018).

Total accumulated revenues for all locations

Currently two slaughtering policies are carried out to generate revenues for each location. They are 1. Continuous slaughtering based on exceeding biomass and 2. Discrete slaughtering, emptying the location for next release. In this model revenues for individual locations are counting separately. Revenues from different locations accumulate in "Total Accumulated Revenue for all Locations" to have an income overview and calculating gross profit/loss at any point of time. Figure:33 shows the total accumulated revenue calculation structure of the model.

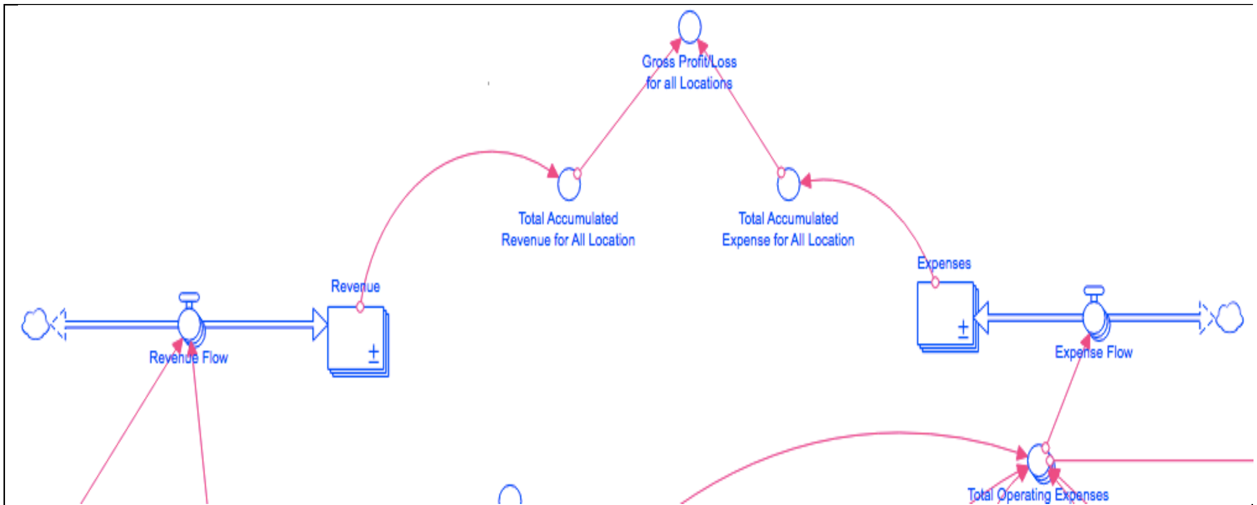


Figure 33: Gross loss-profit calculation structure.

Expenses

The expense stock (Figure: 33) accumulates all the expenses incurred by the fish farm for producing biomass. Direct inputs to the production are only considered here. Expenses are incurred daily, as long as production continues. Since some of the large expenses are incurred in a discrete time.

Total accumulated expenses for all locations

This is a very important variable for calculating total loss-profit of a company. Figure:33 shows individual location expenses are counted separately that can give an expense overview of a particular location at any point of time. Expenses for all the locations are accumulated to the variable called "Total Accumulated Expenses for all Locations". At any point of time anyone can get the amount that has already been used for the production.

Gross loss-profit for all locations

This is one of the key indicators for the management to understand how the company is performing to its core business. Figure:33 illustrates, gross loss-profit is calculated, subtracting all the expenses incurred from all the revenues earned for any point of time. Any positive numbers build confidence on the economic, yet negative values can anticipate apprehension on the operations of the farm. This is not the only parameter to judge a business, yet an effective indicator. For that reason it is considered the key performance indicator to judge the business. The value of this variable refers whether this business is profitable or not. Based on the result of this variable, policies are suggested to improve the business economic. This is also a validation parameter for rest of the model.

Net Harvested Weight

Net harvested weight is a function of total harvested fish multiplied by net weight per fish. Net weight per fish is calculated after gutted. For this industry it is 86% of the base weight (Osland, 2018). For this model net harvested weight (Figure: 33) is the only source to generate revenues.

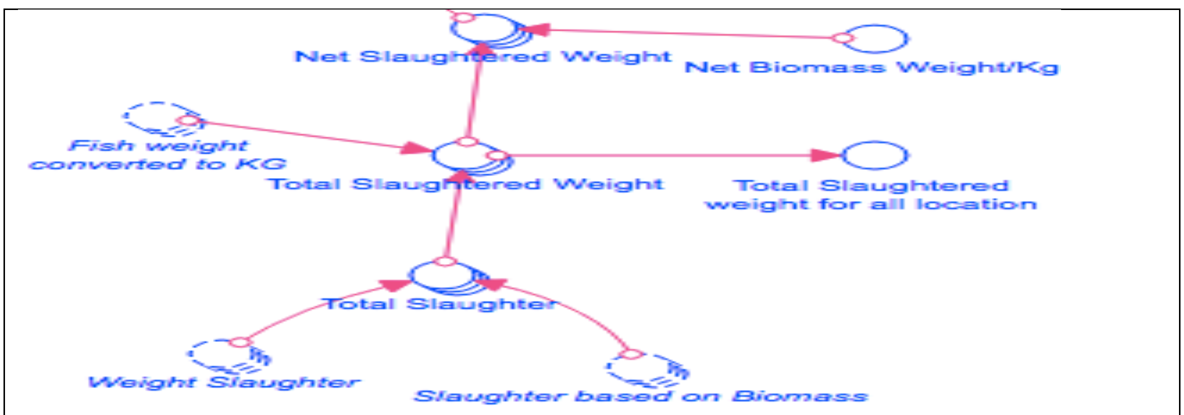


Figure 34: Net harvested weight calculation structure.

Fish market price

Fish price is the value farmers earn for producing biomass. Fish prices are fixed based on the size and attributes of a fish. These numbers fluctuate over time. For the purpose of the model, fish attributes (dimension, color, meat quality etc.) are disregarded. Figure: 36&37 illustrate, five years historical salmon market price for different weight classes (3-4Kg and 4-5Kg) are used to calculate total revenue and observe the business performance. Figure:38 demonstrates comparison between sales prices for weight classes (3-4Kg and 4-5Kg) are performed to observe the relative effect between those weight classes. Figure:35 illustrates the fish market price calculation structure of the model.

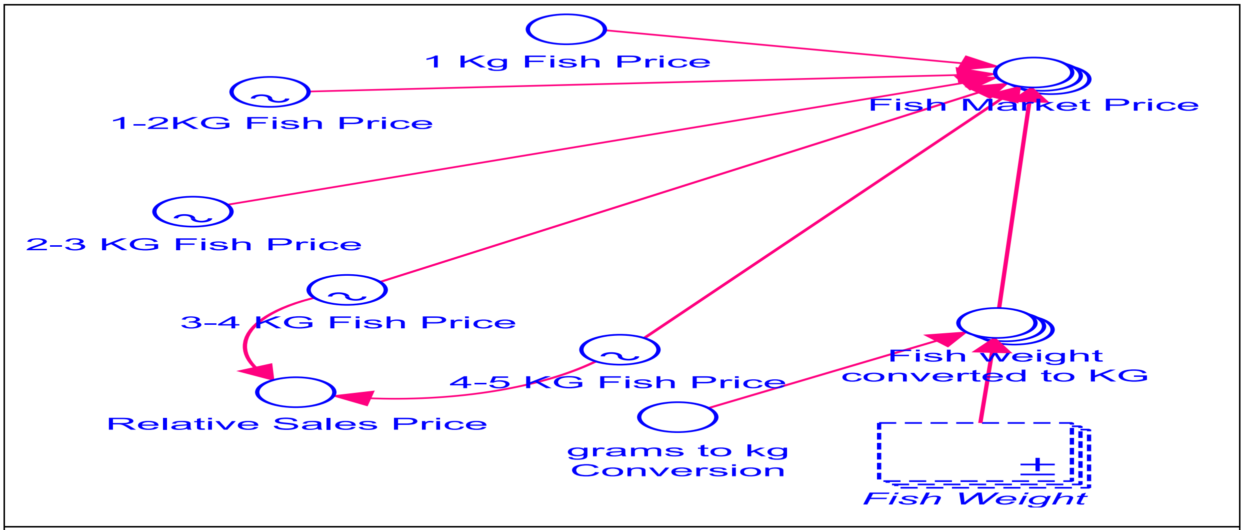


Figure 35: Fish Market price calculation for different weight classes.

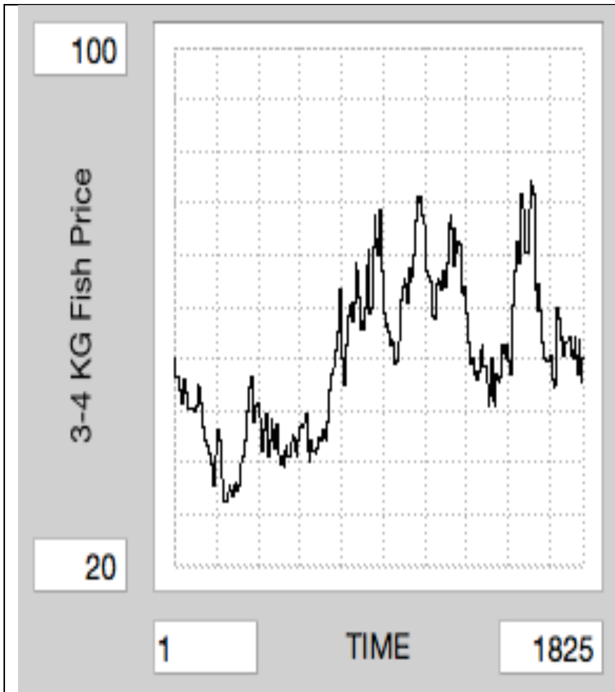


Figure 36: Market price for 3-4Kg Salmon

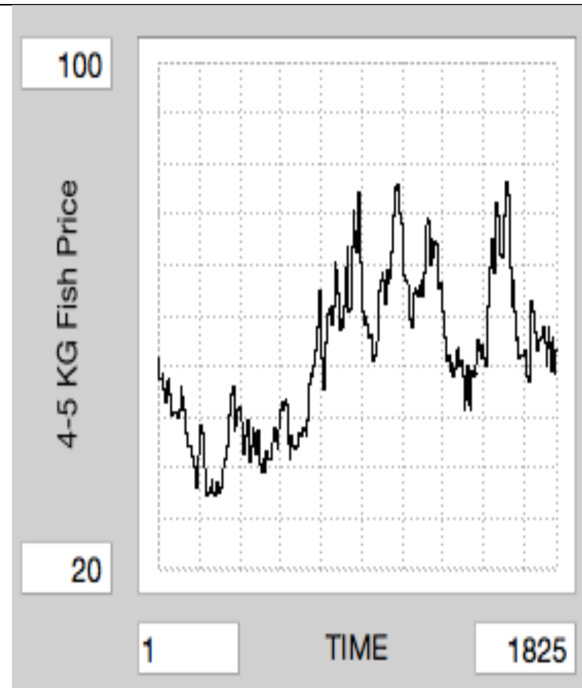


Figure 37: Market price for 4-5Kg Salmon

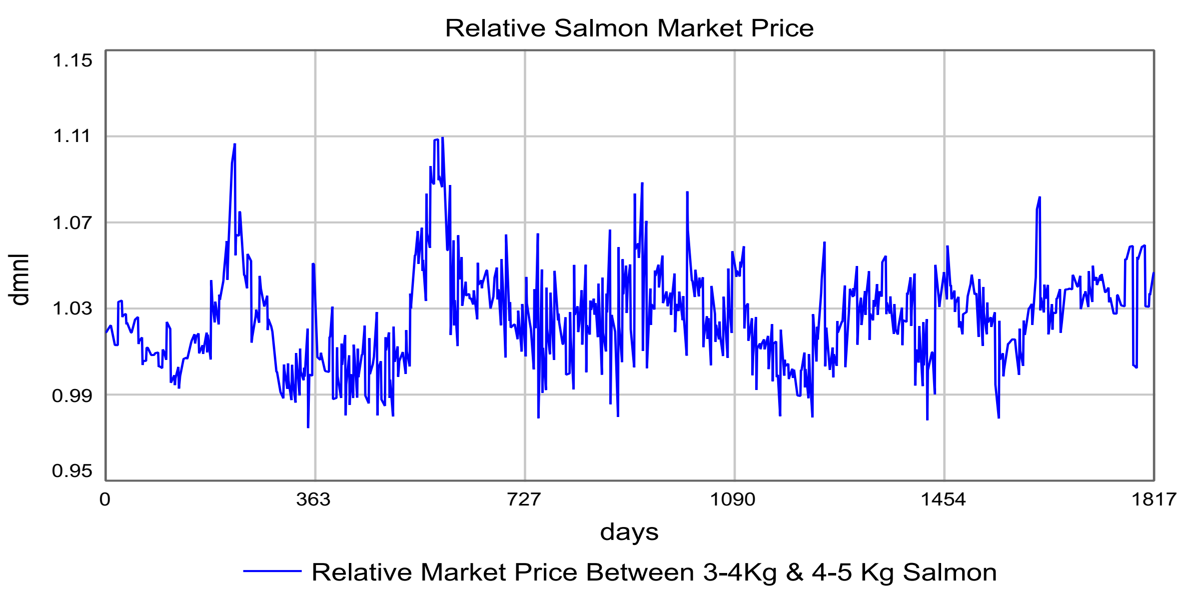


Figure 38: Relative salmon market price comparison between weight class 3-4kg and 4-5kg.

Total operating expenses

Total Operating expenses accumulate total labor costs, total feeding costs, smolts costs, treatment costs and slaughtering costs. These costs are directly involved to produce fish in the aquaculture industry. Operating expenses for each operation are calculated separately. Expenses from different locations are accumulated to a variable called "Total Direct Expenses for all Locations". It is possible to check the incurred accumulated operating expenses form the variable at any point of time.

Total workforce cost

Total workforce cost is calculated based on the total biomass produced. Based on the production, workforces are divided into fixed operational workforce and temporary workforce. Fixed operational workforces are always employed even if the location does not produce any biomass. These workforces carry out necessary maintenance of the site when there are no fish.

Temporary workforces are calculated based on the produced biomass. For every 300000 Kg fish one extra workforce is needed (Osland, 2018). So these workforces are employed when there is enough biomass produced. Total workforce is the sum of the operational fixed workforce and temporary workforce. There are four locations for this model. Workforces per location are calculated dividing total workforce by the number of those locations. Standard compensation package is considered to calculate total labor costs. Figure:38 illustrates the workforce calculation structure of the model.

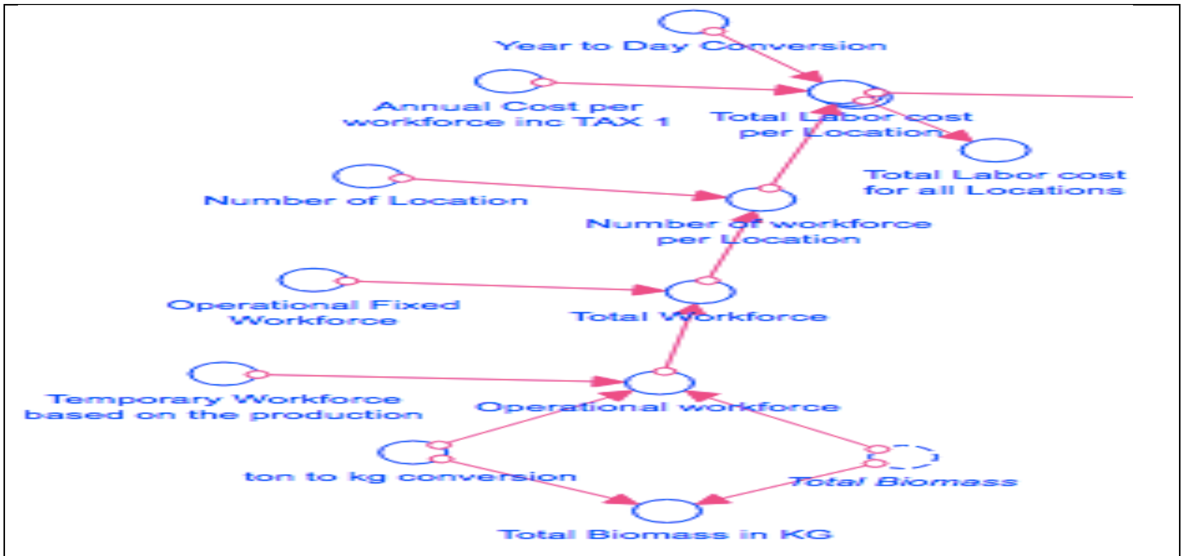


Figure 39: Total Labor cost calculation structure.

Total feeding cost

Feeding is one of the major inputs for fish production. Feeding cost is the direct cost for a production and it incurs every day. When the fishes are small, they grow fast with little food but as it grows bigger, it needs more food comparing to its growth. So the feeding cost is higher when the fish reaches to the saturation. To produce 1 kg salmon, feeding alone takes up approximately half of the total production expenses (Osland, 2018). So, feed cost is a concern from an economic point of view since it reduces the cash flow. In this model, feeding cost per kg is set 15 NOK (Osland, 2018). Feeding cost depends on the feed quality and conversion rate. The best quality feed with a higher conversion rate costs more than the average quality feed. In the growth sector of the model total feed required per fish is calculated (McConnell , 2018). Total feed required per fish is multiplied by total number of fish to calculate total food consumption per day per location. By accumulating the feed amount of all the locations, the “total feed required for all location per day” is calculated. Figure:39 illustrates total feeding cost calculation structure of the model.

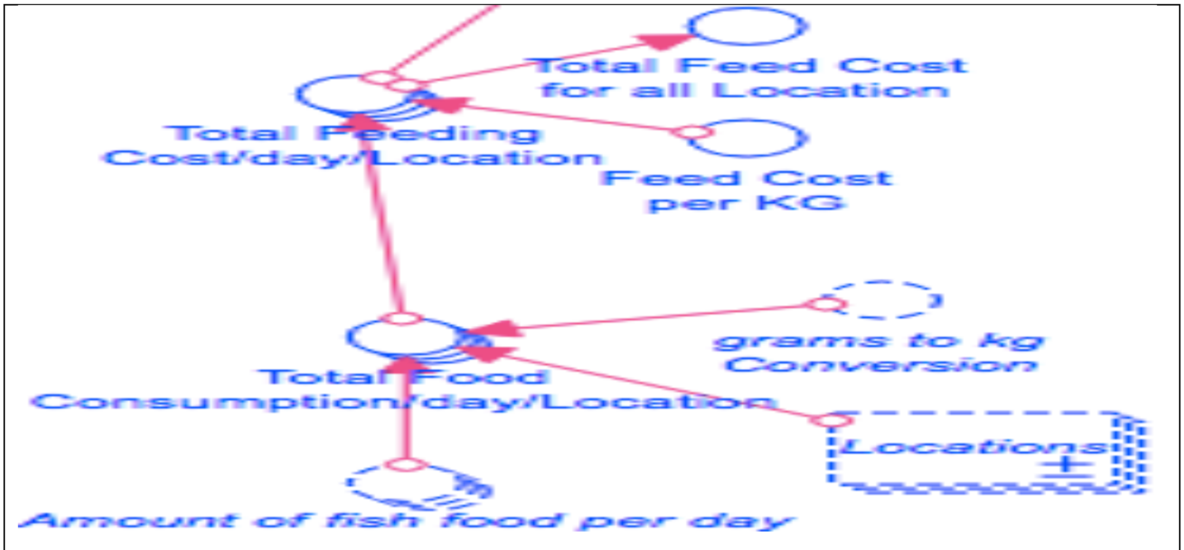


Figure 40: Total Feeding cost calculation structure

Smolt Cost

Smolt is the core input for a fish farm. Production starts with releasing smolt to a location. Somlt production costs are not explicitly calculated for making the economics model simpler. An assumption is made for this model that this company buys smolts from external sources. Price per smolt is modeled based on their weight classes. This smolt price covers all the cost related to the smolt production and their transportation to the site. Smolt costs are calculated separately for each location. Total smolt cost is calculated by summing up all the location's smolt cost. Figure:40 illustrates the smolt cost calculation structure of the model.

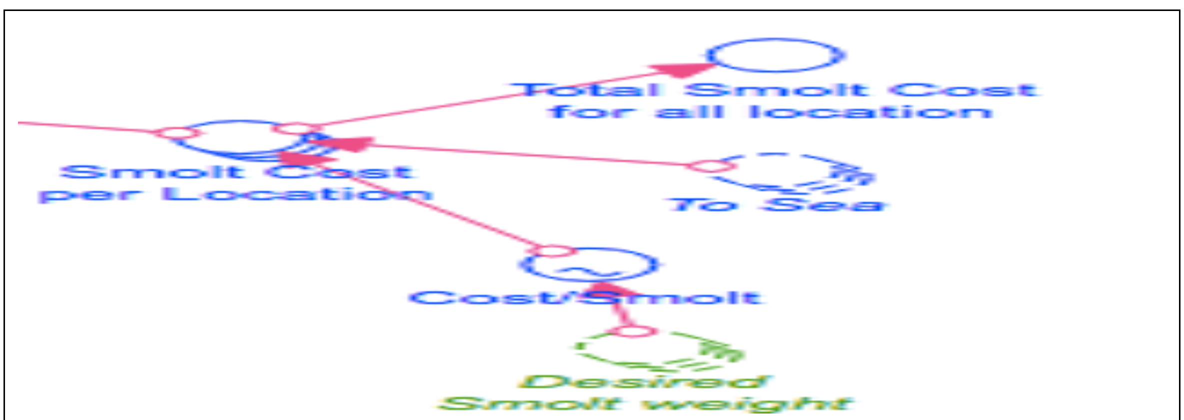


Figure 41: Total Smolt cost calculation structure.

Harvesting cost

Harvesting cost is another important cost for fish farms. Every slaughter increases expenses. Slaughter can be done in-house or outsource to other companies. Harvesting cost can be counted either per fish or per Kg. To keep the calculation simpler NOK 2 per Kg fish slaughtering cost is used for this model (Asche & Bjørndal, The Economics of Salmon Aquaculture, 2011). To calculate harvesting cost per location total slaughtered weight for that location is multiplied by the harvesting cost per Kg. At the end, harvesting costs for all the locations are added together. The sum of these harvesting costs calculates the total slaughtering cost for the farm. Figure:41 illustrates the harvesting cost calculating structure of the model.

Figure 42: Total harvesting cost calculation structure

Treatment Cost

Treatment cost is one of the major and expensive costs for fish farms (Osland, 2018). There are several diseases that can affect severely to fish health. Addressing problems at early stages and medicating properly can cure most of them. But few of them can turn in to the deadliest and wiped out the entire production. So farmers need to be very cautious on fish health all the time. Among the other health problems sea lice is a very common problem in fish farms. Sea lice grow with the fish biomass growth. It can be transported by wield fish stocks from one location to another. Also the eggs can be spread through the water current (Thorstad, 2017). Only female sea lice are dangerous for the fish health and there are precise guidelines to treat them. Since this is a prime and complex problem for the fish farms, an explicit sea lice sector is modeled (Hesleskaug , 2018) and integrated to understand the dynamics. Total treatment costs are calculated based on the different treatment policies and the number of fish are treated to a location. Figure:42 illustrates the total treatment cost calculation structure of the model.

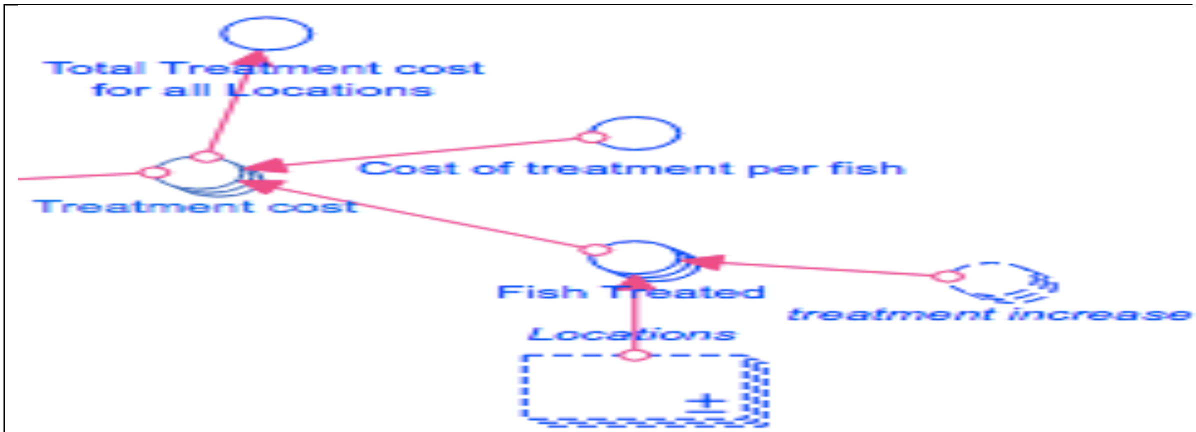


Figure 43: Total Treatment cost calculation structure

Per Kg fish production cost

Per Kg fish production cost is an important indicator to assess the production efficiency. This part of the model describes a unit production cost for a fish farm. All the direct expenses are accumulated to a stock named "Direct Expense" and distribute accumulated slaughtered weight over direct expense to calculate the "per kg production cost". Figure:43 illustrates the "per Kg fish production cost" calculation structure of the model.

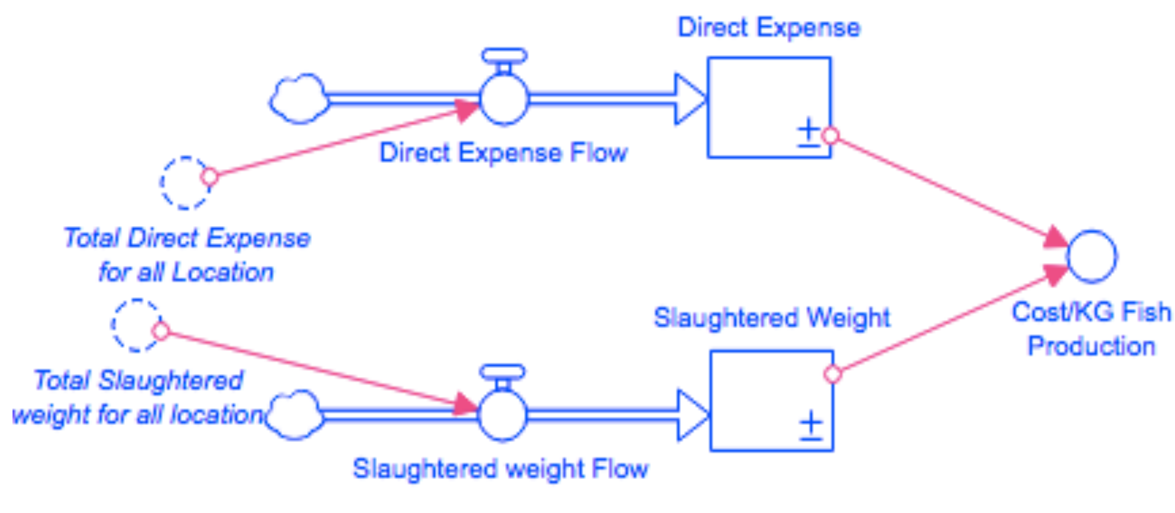


Figure 44: Per Kg fish production cost calculation structure.

3. MODEL ANALYSIS AND TESTING

The primary focus of the economic model is to give a practical illustration of the financial operations of a fish farm and validate the production model behavior. The extended purpose is to find out bottlenecks of the current operation and optimize profitability by eliminating constraints and increasing production yield. However, due to information sensitivity and business strategy, published economic data on salmon production seems scarce. Also, a very few direct financial figures and analysis are provided by Osland Havbruk (Osland, 2018). With this limited scope, a reference financial mode is constructed during replicating reference fish growth. Since, the production model is replicating the reference growth of the fish (Figure: 45), the economic figures during that state are considered as the reference financial points for the farm.

Osland Havbruk (Osland, 2018) has conducted some experiments on the salmon growth by using different smolt sizes. They have provided a graph (Figure: 44) with those experiment results, which is considered as the production and growth reference mode for this model. Figure:45 illustrates the simulated model behaviors that fairly exhibit the fish growth pattern, provided by Osland Havbruk (Osland, 2018) (Figure: 44).

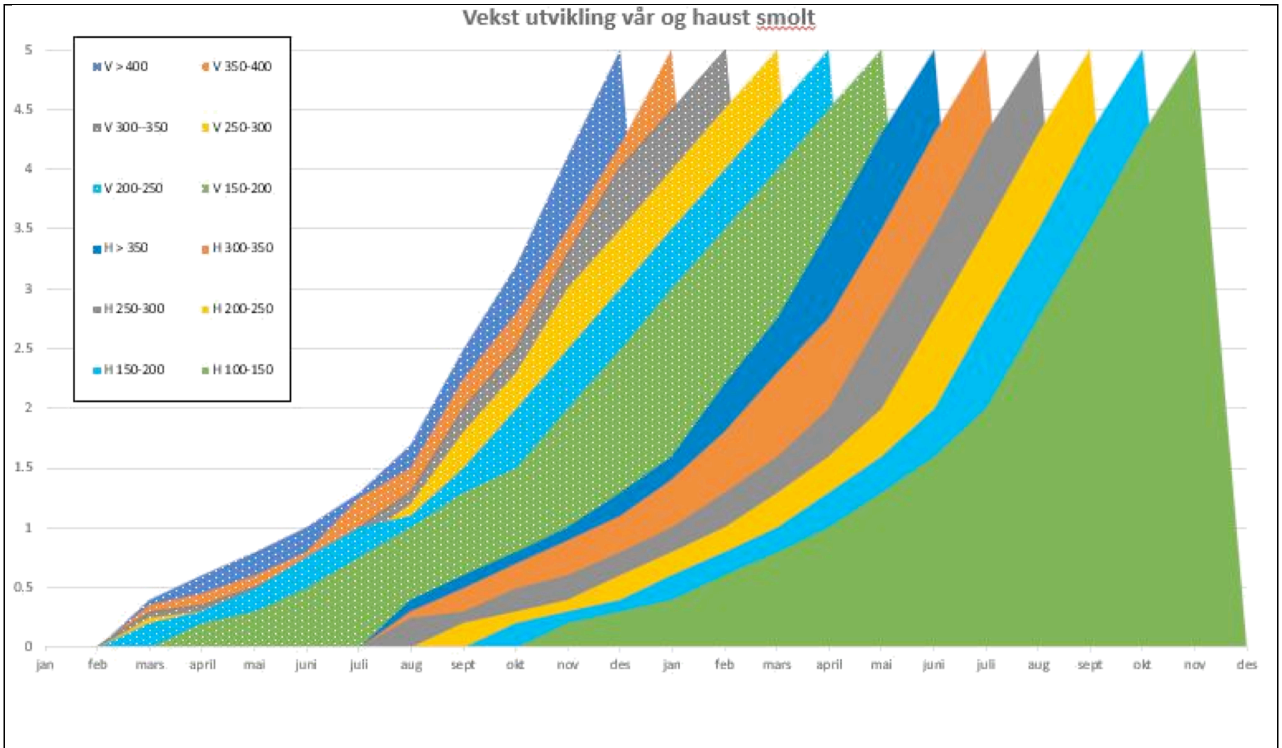


Figure 45: **Fish Growth Graph by Osland Havbruk (reference behaviour graph)**

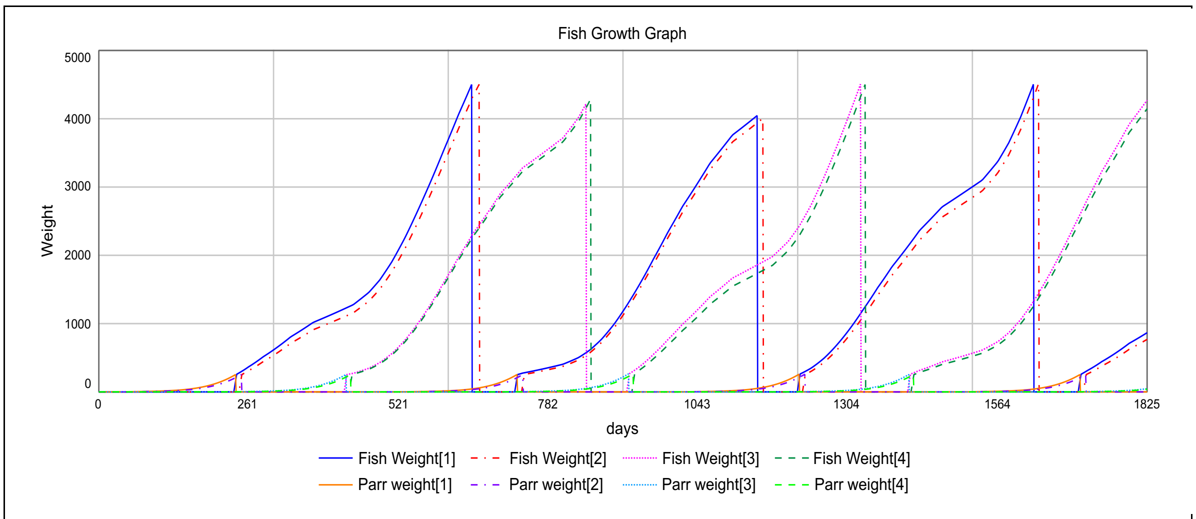


Figure 46: Simulated Fish growth graph

In the reference graph, the left light blue curve represents the spring introduction, while the right yellow curve presents the fall introduction, where 200gram – 250gram smolts are used. In the simulated graph fairly similar pattern is exhibited with the similar smolt size (250grams). It takes around 14 months to complete a production cycle. However, simulated result shows faster fish growth comparing to the reference mode. It is happening due to the ideal conditions of the model. Nevertheless, both the reference mode and simulated graphs has exhibited a faster growth pattern during the warm temperature in summer (spring release) and a slower growth during the winter (fall release).

To establish a reference mode for the financial model, several key components are considered during the core production model replication. To judge the core economic status with the current production capacity, MTB utilization, Loss-Profit statement and per Kg production cost are the prime financial elements among the others that need to be studied. These key components are set as the economic reference point to validate the model and test the policy outcomes.

Maximum Total Biomass (MTB) Limit

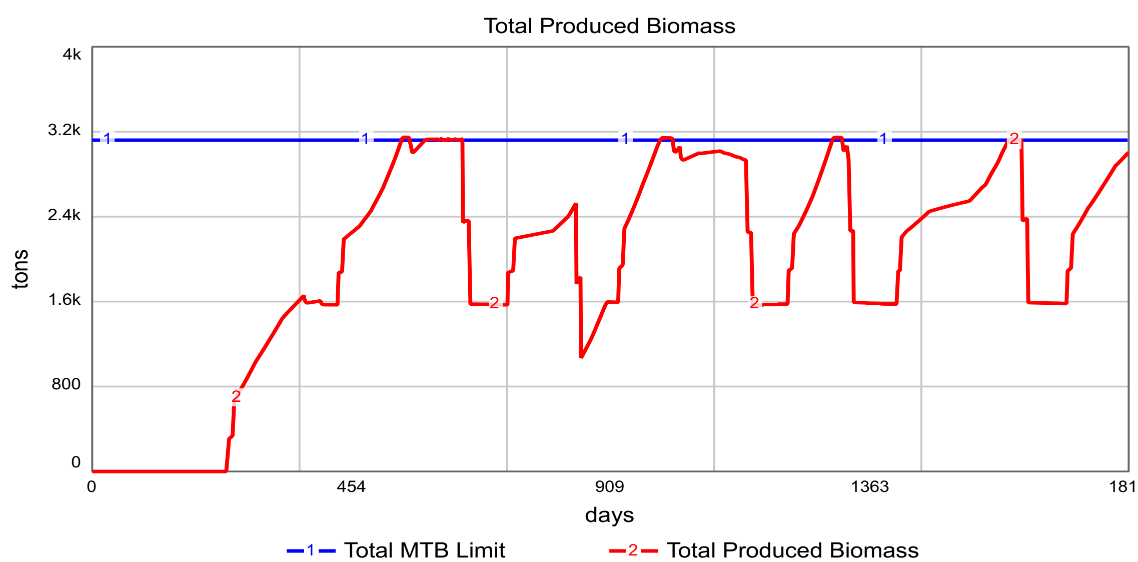


Figure 47: Total produced Biomass capacity utilization, which is one of the reference points for the economic model.

MTB is considered the most scarce and expensive resource for a fish farm operation (Osland, 2018). Efficient utilization of MTB can ensure sustainable profitability for the fish farm. Thus, MTB utilization is one of the key indicators to identify the current capacity utilization. Efficient MTB utilization makes a salmon aquaculture production profitable. According to the Norwegian regulation, license and locations are required to establish aquaculture operations. A license has maximum biomass production limit to 780 tons that is known as the maximum total biomass (MTB) limit (Osland, 2018). License is connected with the locations to enable the farmers having flexible production throughout the year. MTB utilization is the most complex factors to design a salmon aquaculture production plan. Sometimes the complexity turns to a problem since the farmers are not only obliged to ensure the total biomass cap but also responsible to prevent the production exceeding the MTB limit for any single location. Thus, during production planning, farmers need to ensure enough locations for flexible production to maximize output and achieve a satisfactory MTB utilization. Figure:46 illustrates the current biomass production status of the farm during the production model replication. The result represents 60% of the total MTB capacity utilization. That means 40% unutilized capacity remains. However, It is worthwhile to consider, utilizing those idle capacity can enhance to achieve potential "economies of scale". Thus, current MTB utilization status (Figure: 46) is set as the reference point for the economic model.

Loss-Profit statement

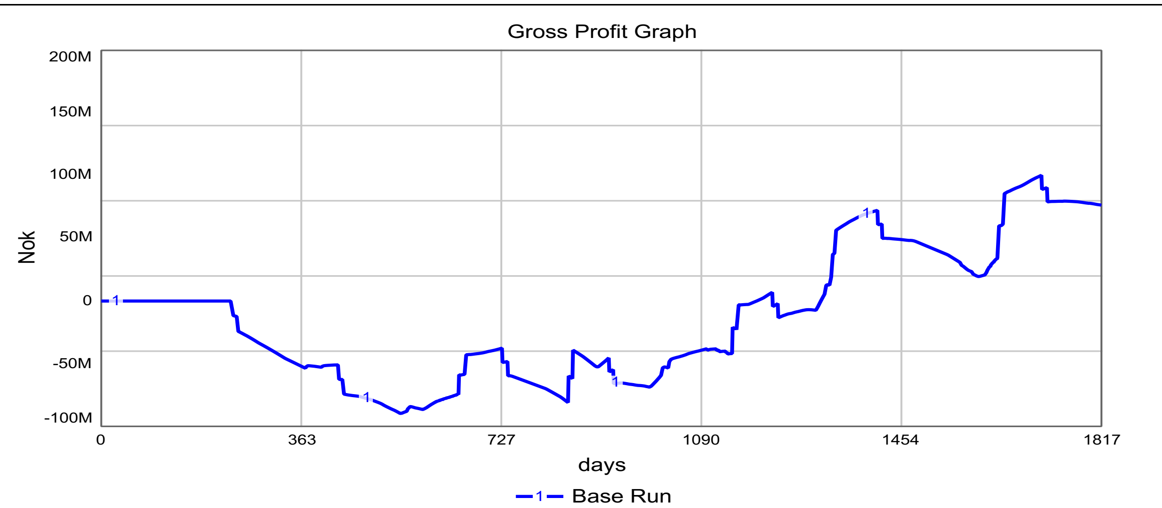


Figure 48: Simulated gross loss-profit result that is one of the reference points for the economic model.

Among the others, improving the current profitability by increasing production quantity and reducing production cost is one of the core focuses of this study. While the simulated production model reproduces the reference mode, economic model exhibits the above gross profit value (Figure: 47). The gross profit result is considered as one of the reference points for the economic model. From the economic model, simulated MTB utilization result (Figure: 46) gives an indication of 40% unused capacity, which gives an impression that the farm is not making reasonable profit by applying the current business model. The result shows, it takes around three years to reach the breakeven point. The incurred costs are bigger than the accumulated revenue at the beginning. Once the breakeven threshold is overcome, the business looks profitable towards the end of the simulation.

Cost of production per Kg salmon

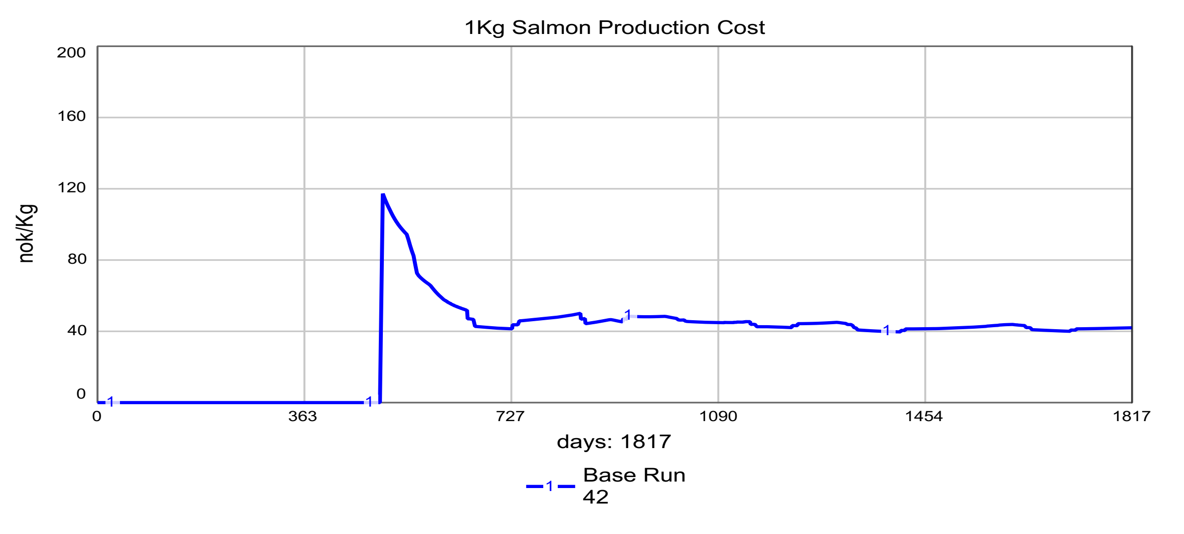


Figure 49: Per Kg Salmon Production cost that is one of the reference points for the economic model.

Per Kg Cost of production is another important parameter to understand the current production efficiency of a fish farm. Figure: 48 is set as the "per Kg salmon production cost" reference price for the economic model. The result demonstrations the average production cost for 1kg salmon in the current business model. This parameter indicates how the current production volume distributed over the total direct production cost, perhaps operational efficiencies of the fish farm. The farm can set profit margin by comparing current market price with the “per Kg production cost”. Simulated result shows (Figure: 48) “per Kg production cost” reach to the peak at the beginning because of the incurred accumulated cost is higher than the slaughtered weight. Over time, accumulated production volume is distributed over the accumulated costs and stabilized the “per kg production cost”.

Model Testing and Validation

Biomass growth, harvesting decisions and treating diseases are at the core of the operations of any fish farm. To judge the core performance of such a business, among others, financial overview is one of the very important indicators. Management and stakeholders are always considering economic values as a strong leverage point to visualize a business from different perspective. Keeping that in mind an economic model is integrated to this fish production model.

Testing is an essential part to validate and build confidence on the model. Validate the model is one of the important factors to ensure the reliability of a model. Purpose of the model drives the entire validation process. Several formal tests are needed to validate the model. However, no amount of testing can entirely validate a model rather building the confidence on it. But model validity cannot be entirely based on formal procedures (Barlas, 1996; Forrester & Senge, 1979; Sterman J. , 2000). However there are formal standards and guidelines available in the literature. Validation testing of this study has been carried out following those formal guidelines. To build the confidence on the model, two major validation tests are performed. Structure validation and model behavior validation. Structure verification includes comparing model structure with the real system (Forrester & Senge, 1979). In this study structure validation and parameter verification tests are compared with the real fish production process following by Osland Havbruk (Osland, 2018). In addition extreme condition and dimensional consistency tests are also performed to build further confidence on the model.

On the other hand behavior test "evaluate adequacy of model structure through analysis of behavior generated by the structure (Forrester & Senge, 1979). "Behavior reproduction test " and "behavior sensitivity tests" are belong to this group. The simulated behaviors are evaluated with the reference mode behaviors through behavior reproduction test. Figure46 illustrates the simulated fish growth graph that is able to reproduce the reference behavior pattern, provided by Osland Havbruk. Sensitivity test ensures the right reasons for the model behavior, even after the model is able to reproduce the reference behavior. Couple of sensitivity tests is conducted and discussed in this section to build the confidence on the model.

Cost components those are directly related to the production cost needs to be adjusted for the differences in production time and quantity produced. Among others feed cost is a concern from an economic point of view since it reduces the cash flow. Fish growth has a strong relationship with feeding. Feed conversion ratio represents the relationship between the feed quantity and the fish growth. Figure 53 illustrates feed quantity varies over time according to the growth of the fish. To ensure the model is producing right behavior for right reason senivity analysis on feed conversion ratio (FCI) and feed cost per kg are conducted. The changing effects of gross profitability for those variables are discussed below.

Sensitivity Analysis: feed conversion ratio (FCR)

Feed conversion ratio refers the efficiency of converting food into the desired output. For the salmon aquaculture FCR is 1.5 that means 1.15 kilos of feed gives one kilo of meat. Salmon can utilized the feed most efficiently among the other livestock because it has the same body temperature as the water and does not use energy to keep the body warm. So how the growth can be affected by changing the FCR is discussed here.

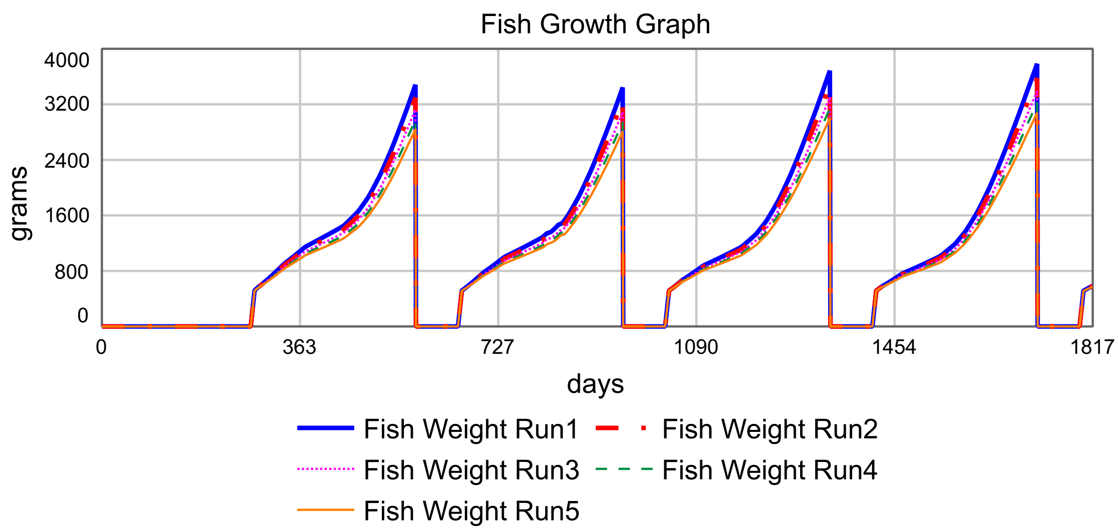


Figure 50: *Sensitivity analysis between the Fish growth and the feed conversion ratio (1.05-1.25)*

Figure50 illustrates the sensitivity between the fish growth and feed conversion ratio. FCR range between 1.05 to 1.25 is used to check the growth pattern. Simulation result clearly shows lower FRC expedite the fish growth and higher FCR slows down the growth.

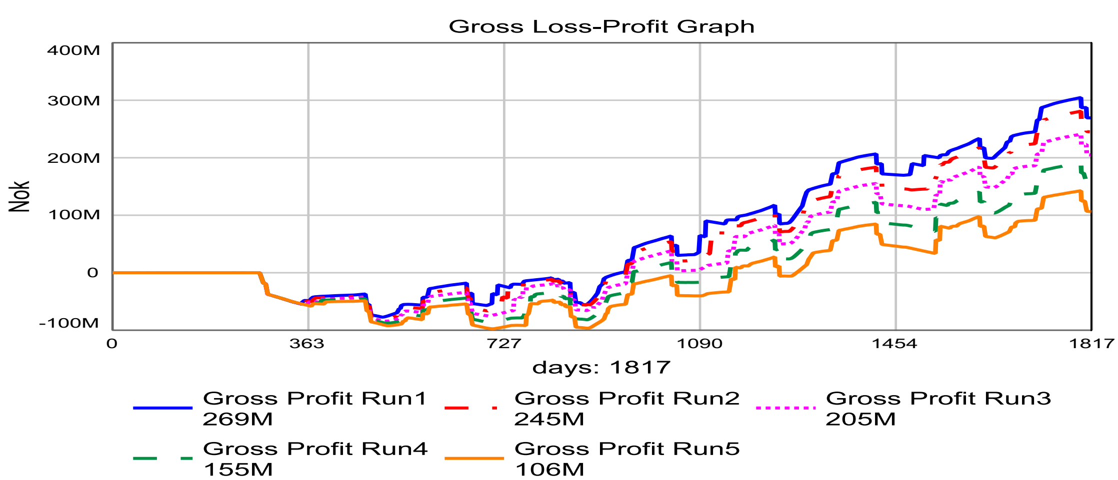


Figure 51: *Sensitivity analysis between feed conversion ration and profitability.*

Figure51 shows feed conversion ration is very sensible to gross loss profit generation. When FCR is 1.05 total profit riches to 269 million. That means profit is increased by

31% by increasing 10% efficiency in food conversion ratio. On the other hand profit reduced by approximately 50% by reducing the FCR by 10%. From the above figures and facts it is certain that the FCR is very sensible to the fish growth and the profitability.

Sensitivity Analysis: per kg feed cost

Feed cost is directly affecting the direct production cost and gross profit. So a sensitivity analysis is conducted to check how does it affect to the gross profit by changing feed cost 3 NOK in each direction.

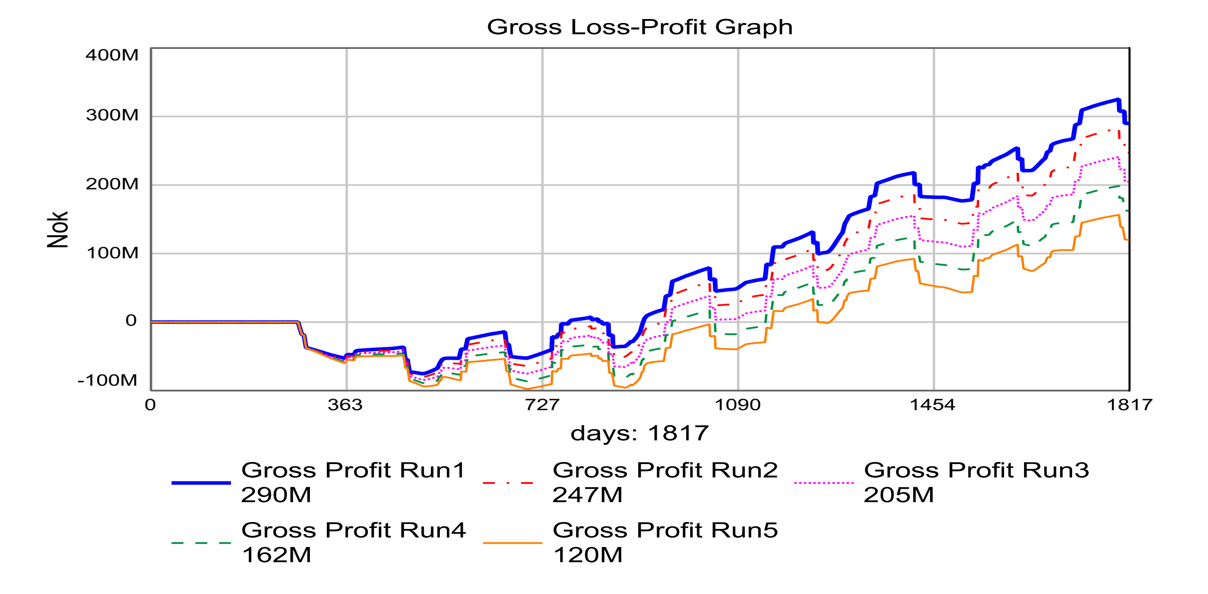


Figure 52*: Sensitivity analysis between per kg feed cost and profitability.*

Simulation result shows 3 NOK drop in per kg feed cost can elevate the gross profit by 85 million NOK. That means 20% changes in per kg feed cost increases gross profit by 41%. So from the analysis it is observed that the fish farms profitability is highly sensitive to the feed cost.

Extreme Condition Test:

Extreme condition test ensures the matching between simulated and real system behavior even after providing inputs well out side of the normal values. For the productions model any negative fish or negative weight is unexpected even the feeding is zero. In the economic model when there are no fish remains in the stock total revenue and expenses should not go below zero. To experiment this the variable "time to next hatching" in the growth and production sector is set to 0. So there will be no hatching after the first group is hatched. As a result there will be no smolt to release in the sea.

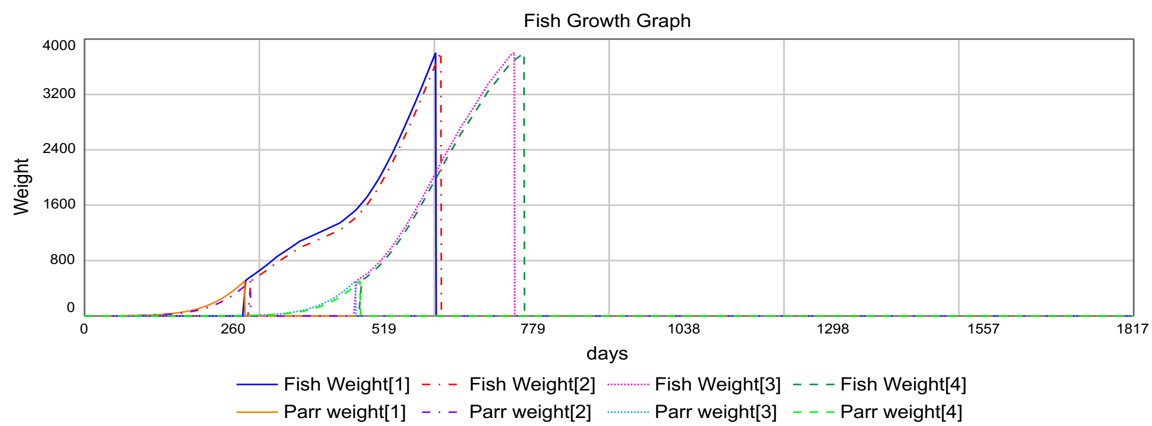


Figure 53: *One group of fish weight gain.*

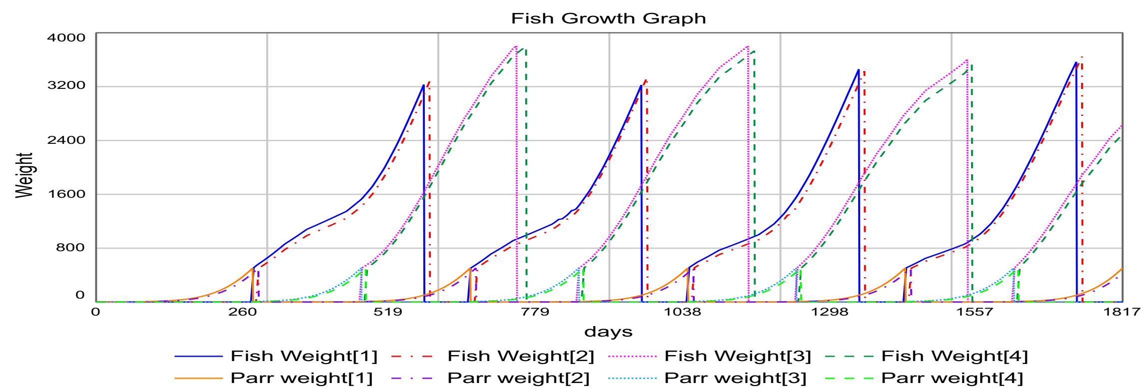


Figure 54: Full production cycle as per reference mode.

Figure: 53 & 54 illstrates the full production cycle and one production cycle. As are no smolts are released to the sea after one production cycle there are no fish growth, means no fish in the stock. In the economic model the accumulated revenue and expenses are also become zero after completing the first production cycle.

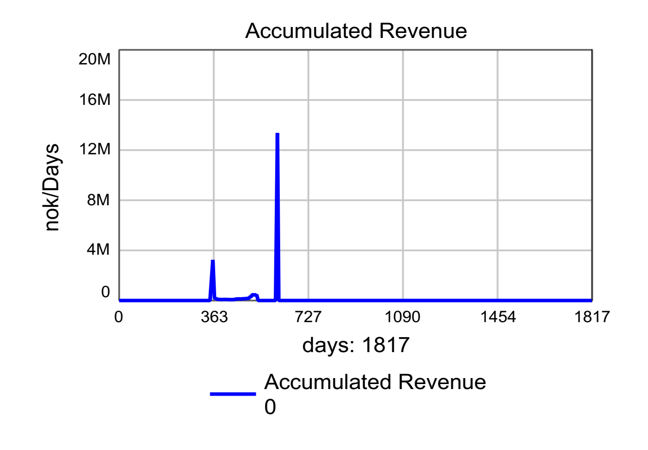


Figure 55: Revenue after first production cycle

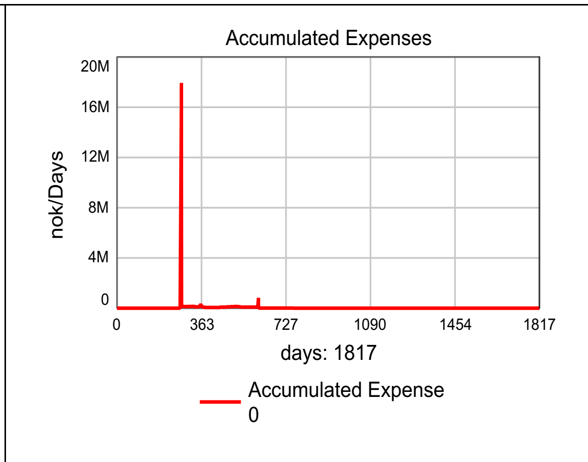


Figure 56: 57: Expenses after first production cycle

Figure 55 &56 demonstrates the model is producing correct behavior and that ensures the structure accuracy.

4. POLICY RECOMMENDATIONS

A policy indicates how time, information and uncertainty can create incentives or difficulties for a particular decision. A number of variables determine profitability in aquaculture, including capacity utilization, biological factors, capital investment, operational costs and sales price. Many of the actual outcomes in the aquaculture, rely on a healthy environment and MTB utilization level. To ensure the suitable production environment, the exploratory simulation model has been analyzed, tested and validated with the reference mode behavior. During the analysis, it is perceived most of the problems are dormant under inefficient capacity utilization due to the longer production cycle. Thus, to keep the environment healthy and make the business profitable, MTB utilization level needs to be increased by tailoring the longer production cycle. To reduce production time and improve operational process, two promising policies regarding smolt and harvesting are tested as tentative solutions. The policy experiments are run based on several assumptions.

6. The key purpose of the economic model is to calculate the financial figures and analyze the best policy outcome.
7. The plants are fully developed. All fixed costs relating to the plant establishment are disregarded.
8. Smolt production costs are not calculated explicitly rather a fixed price per smolt based on their weight classes are accounted.
9. Even though economic model has disregards the entire smolt production cycle, due to the way production model is constructed, the smolt introduction date is not the day 1.
10. All workforces here are regarded as direct operational costs.
11. Money is not a limiting constraint with respect to the operations.
12. This model is only taking inputs from the biomass growth and lice sectors but not giving any feedback.

This chapter discusses those policies and their effects

Policy 1: Early Harvesting

Early harvesting can reduce production uncertainties, increase production intensity and ensure maximum capacity utilization, without altering traditional farming process. A working paper on “Patterns in the Relative Price for Different Size of Fish: Biological Price Generating Process in Fish Farming” by (Asche & Guttormsen, 2001) has argued on finding effects to the relative price of the different weight classes. Thus, the relative market price is compared with the additionally incurred production cost.

Harvesting decisions are one of the key determinants to optimize production cost and ensure profitability. “Post smolt” phase is considered the most vulnerable and riskiest period for the traditional salmon aquaculture for various uncertainties. For instance, outbreaks of parasite are the most inevitable challenges fish farmers are combatting recently (Bjørndal & Tusvik, 2016). A severe lice outbreak can lead to slaughter the entire fish stock by the legal authority (Bennich, 2015). On the other hand, fish escaping can be fatal for the farmers as well as the wild fish stocks (McGinnity, 2003). Despite, knowing all these common uncertainties, farmers are often intended to grow the fish to the maximum size (between 4kg to 5kg), prolonging the phase to obtain the maximum market price. That shifts their perspectives towards the maximum market price ignoring all the tradeoffs.

To grow the fish larger, it requires more time, more production inputs, which makes the production cost and uncertainties in fish health even larger (Asche & Bjørndal, The Economics of Salmon Aquaculture, 2011). Optimal harvesting decision can be an alternative to short production cycles and eliminate many uncertainties. It can increase control over the production environment, possibly improves capacity utilization to ensure elevated profitability. Moreover, when growth slows down the marginal value, early harvesting can make room for new fish that may grow faster and elevate production yield. However adopting the policy might increase the scarcity for the larger (between 4kg to 5kg) salmon in the market. Thus, to measure the success of this idea, several relative analyses are conducted below.

To test the outcome of this concept an experiment is conducted based on the following parameters.

Table 7: Experiment parameter setting for testing policy 1.		
Variable	**Base Run (Run 1)**	**Policy 1 (Run 2)**
Time to Next Hatching	Day 490	Day 490
Desired Fish Weight	4.5Kg	3.8Kg
Smolt Size	250g	250g
Smolt Introduction to the Sea on	Day 239	Day 239
Harvesting on	Day 650	Day 616
Total Production Time	411 Days	377 Days

The policy is tested (Table: 7) to identify the incentives by reducing desired fish weight from 4.5Kg to 3.5Kg. The experiment is run based on the traditional 250 grams smolt to check the duration to reach the desired harvesting weight between 3.5Kg-3.9Kg. Smolt is introduced to the sea on the day 239 and harvested on day 616. It takes 377 days or approximately 13 months to complete a production cycle that is a month reduction in a production cycle. To keep the smolt flow continuous, "time for next hatching" is set to day 490. To calculate the economic value of the policy, following price estimates (Table: 8) are used (Osland, 2018).

Table 8: Experiment parameter values for testing the policies.		
Variable	**Parameter Value**	**Unit**
Fish Feed Cost	15	NOK/Kg
Annual Worker Cost Inc. Tax	600000	NOK/Employee
Slaughtering Cost	2	NOK/Kg
Smolt Cost	6-10	NOK/Smolt
Treatment Cost	7	Nok/Fish
Estimated Food Wastage	10%	Dmnl

Experiment outcomes

This experiment is run with the affect of lice treatment to observe the effect on lice infestation, resource utilization and loss-profit statement. By running the experiment some curious results are observed on the key parameters. Observed outcomes are discussed below.

Table 9: Experiment outcomes for policy 1.

Parameter	Base Run (Run 1)	Policy 1 (Run 2)
Production Duration	14Months	13Months
Total MTB Utilization	60%	60%
Total Slaughtered Weight	17M KG	17M KG
Total Operating Expenses	715M NOK	689M NOK
Total Feed Cost	448 M NOK	428 M NOK
Total Treatment Cost	13.2M NOK	9.12M NOK
Gross Profit	76.7M	127M
Production Cost for 1Kg Fish	42NOK	40.5NOK

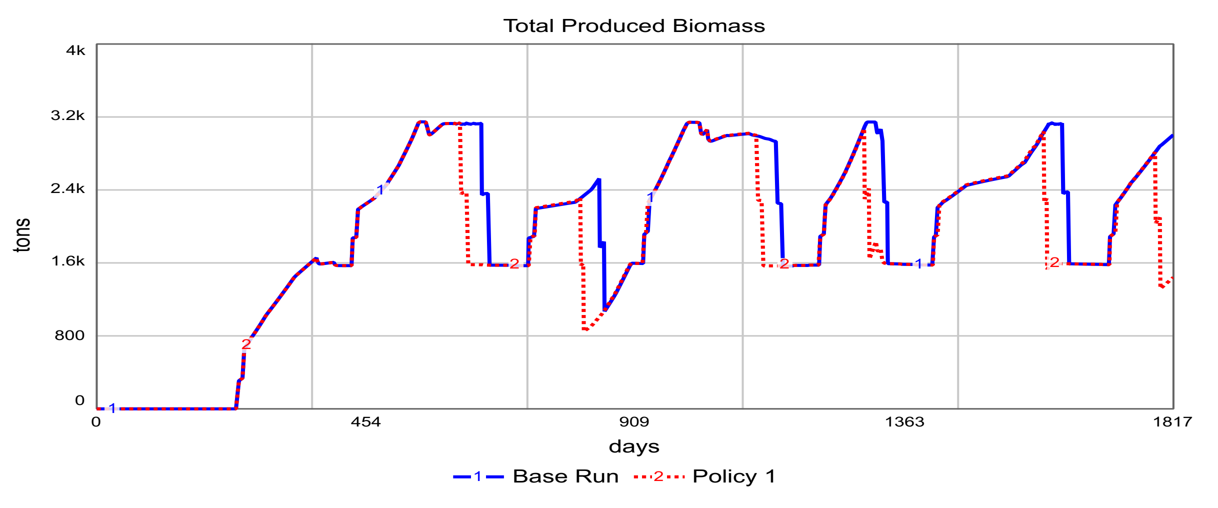


Figure 58: Total MTB utilization comparison between reference mode and policy 1 outcome

In a traditional salmon farming, introducing lower weight class (policy 1) is able to reduce the production cycle by a month. But no noticeable change is observed in MTB utilization during the simulation (Figure: 49). Capacity utilization and total slaughtered weight remain at the same level. That indicates lower harvesting weight is just compensated by a month reduction in the production cycle. However saving 1 month in a production cycle can generate intensives in every 13th production cycle by adding an extra production cycle. From that perspective policy 1 seems effective in the long run.

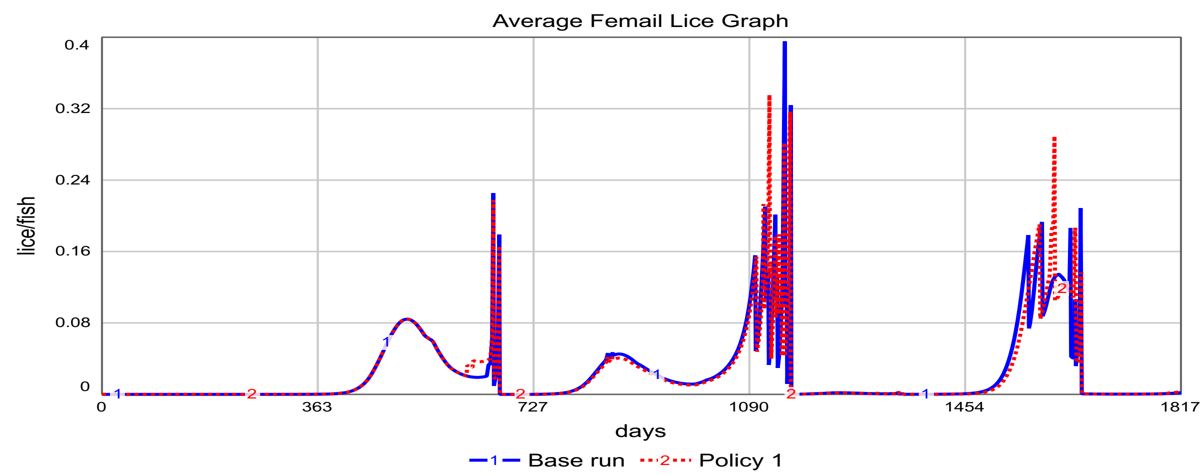


Figure 59: Average female lice infestation comparison between the current production model and policy 1 model.

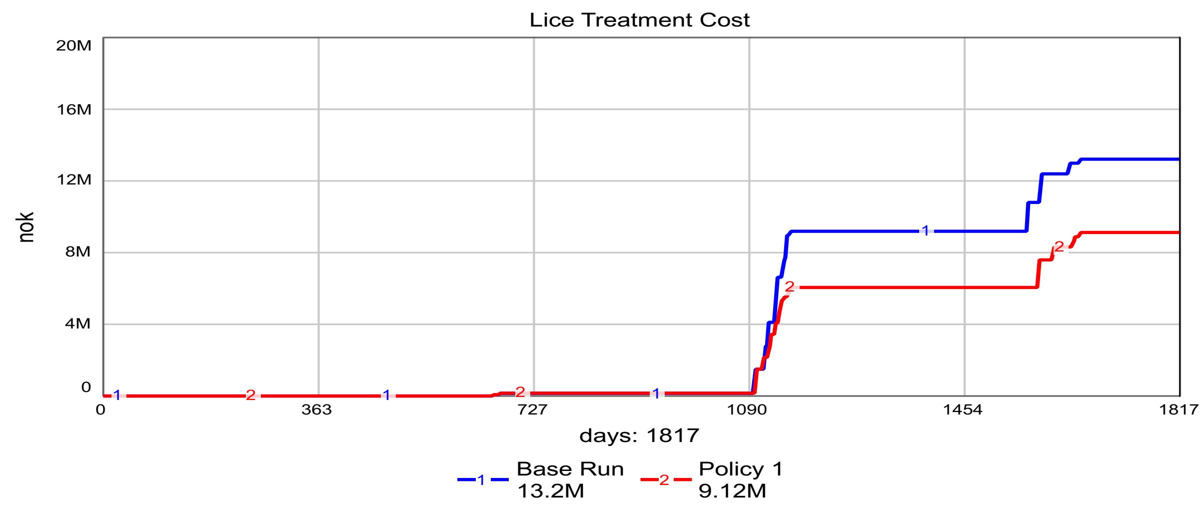


Figure 60: Lice treatment cost comparison between the current production model and policy 1 model.

However, adopting lower harvesting class shows some noticeable changes in lice infestation. Even though the policy produces equal amount of biomass, early harvesting is managed to reduce lice intensity. Figure:50 illustrates reduction in female lice due to the shorter production cycle. That leads to a considerable savings in lice treatment. Figure:51 shows, treatment cost is reduced by 4 million NOK by introducing the policy.

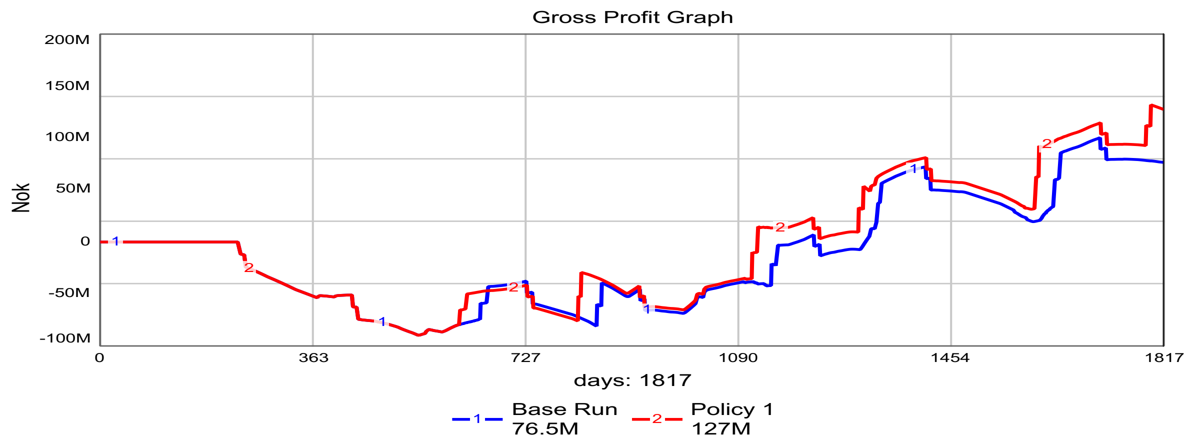


Figure 61: Gross profit comparison between reference mode and policy 1 model.

On the other hand, introducing lower weight class increases gross profit by 50 million NOK (Figure: 52) without changing produced biomass volume and MTB utilization. However shorter production cycle is managed to reduce lice treatment cost by 4 million NOK. To identify the leverage point of the policy, fish growth and relative sales price are analyzed as well.

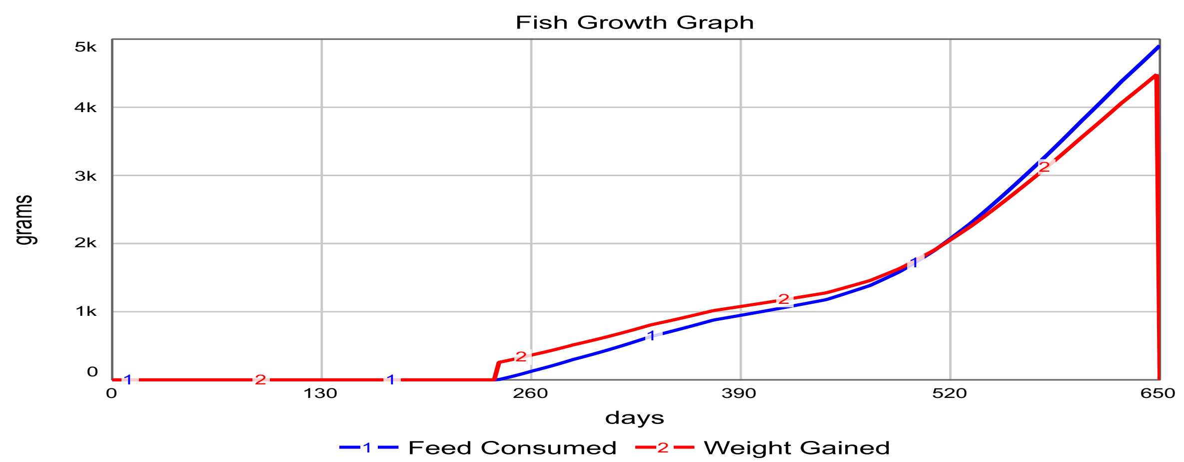


Figure 62: Fish growth comparison with the feed consumed.

Growth has a strong relationship with feeding. Feed conversion ratio represents the relationship between the feed quantity and the fish growth. Figure 53 illustrates feed quantity varies over time according to the growth of the fish. From the growth graph (Figure: 52), faster fish growth is observed comparing feed consumption during the early growth stage. However, the growth gets weaker once the biomass increases to certain level. Feed cost is a concern from an economic point of view since it reduces the cash flow (Asche & Bjørndal, The Economics of Salmon Aquaculture, 2011). Thus early harvesting can make space available for new fish and improve production quantity. According to the graph 2.5kg is the optimum point to harvest where feed consumption and growth are equal. Yet due to the demand of bigger fish and higher market price, an ideal harvesting weight is between 3.5kg to 4kg that can optimize production volume by reducing production cost.

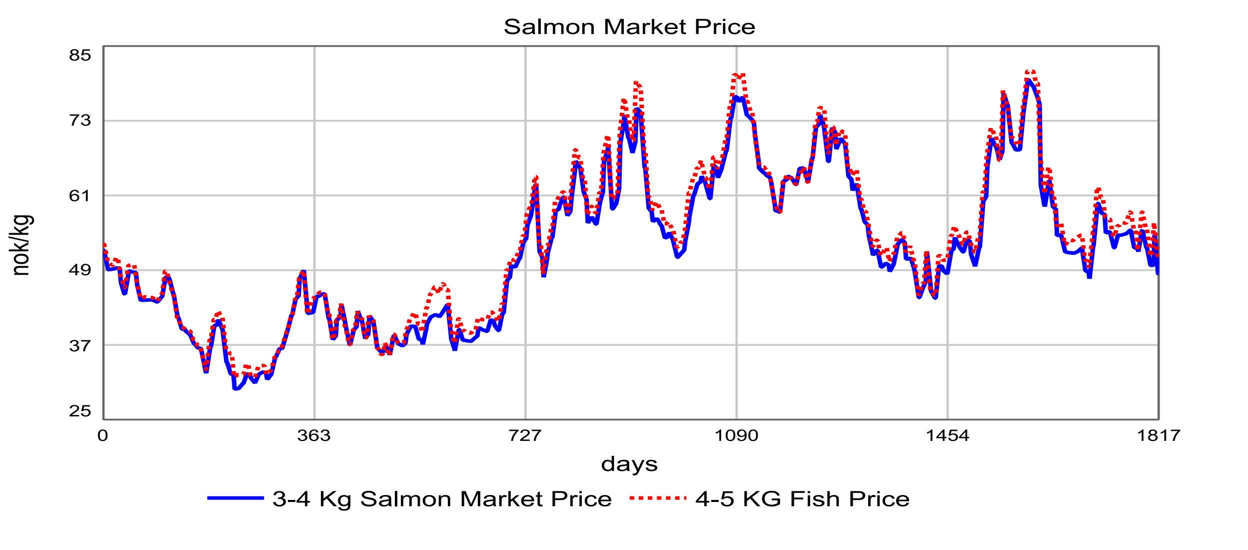


Figure 63: Salmon market price comparison between weight class 3-4kg and 4-5kg.

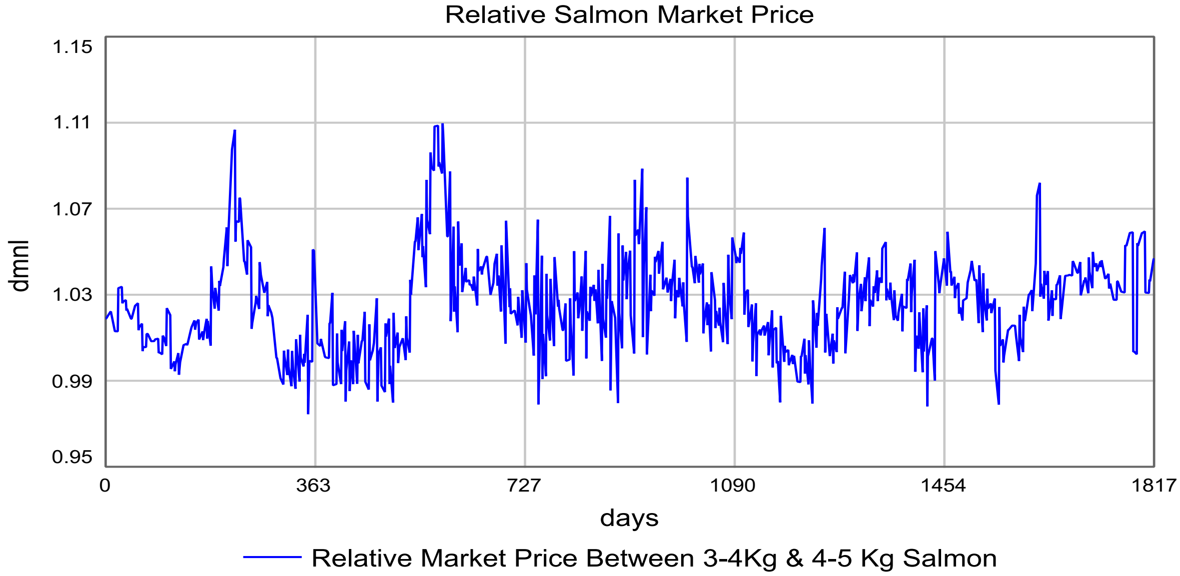


Figure 64: Relative salmon market price comparison between weight class 3-4kg and 4-5kg.

On the other hand market price graph (Figure: 54) shows very insignificant price variation between the fish weight classes. Sales price is one of the major factors to determine profit of a product. To identify the sales price differences, relative market price between two weight classes (3-4kg and 4-5kg) are illustrated in Figure: 55. It is observed from the simulated result that the price relativity between the weight classes is very marginal. From that perspective opportunity cost of introducing lower weight class is fairly reasonable. However the policy enables the fish farm to save production time, limit sea lice exposure and reduce direct production cost.

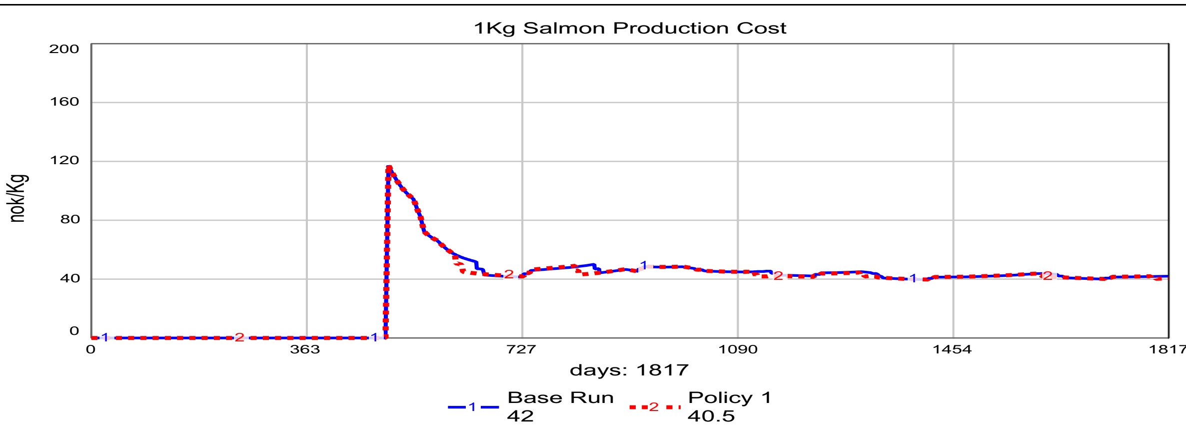


Figure 65: Per Kg salmon production cost comparison between reference mode and policy 1 model.

The simulated policy result displays (Figure: 56) a marginal savings in the total operational cost. The savings are presumed to be an outcome of shorter production duration and lower harvested weight. Saving one month from a production cycle is able to save noticeable amount of feed cost, treatment cost and labor cost. Thus, marginal savings in direct operation cost is able to reduce per Kg production cost by approximately 3.5% that adds value to the profitability.

Policy 1 summary

Introducing lower weight class does not show any changes in the MTB utilization. But early harvesting can make room for new fish that may grow faster and reduce production time by one month. However reduction in production cycle has shown noticeable effect on sea lice infestation and treatment cost. Reduced lice treatments and feed consumptions are managed to save direct operation cost noticeably. As a result 3.5% cost reduction is observed in per Kg salmon production. On the other hand, the relative salmon market price is witnessed very marginal between the weight classes. Thus, the opportunity cost for accepting lower weight class is very insignificant. Considering all these facts the policy seems effective in the long run.

Policy 2: Introduce Larger Smolt

Introduction of larger smolts (500grams) can enhance competitiveness and offer economic gains for the traditional salmon aquaculture. Berget (2016) (Bjørndal & Tusvik, 2016) analyzed the economic outcomes of production, using different size of smolts in the sea pen. This concept supports an extension of the land-based smolt phase, keeping fingerlings on land-based unit until they reach to a significantly large size (between 400grams – 500grams) compared to the traditional release of smolts (between 80 grams – 250 grams) (Bjørndal & Tusvik, 2016). By adopting this policy, it is anticipated that production time and production uncertainties can be reduced significantly, including but not limited to unused capacity, production time, and lice infestation. Controlling some of or all of these uncertainties can certainly manage to improve capacity utilization, increase production volumes and reduce production cost. To test the effectiveness of the concept several comparative analysis are discussed below.

Table 10: Experiment parameter setting for testing policy 2.

Variable	**Base Run (Run 1)**	**Policy 1 (Run 2)**	**Policy 2(Run 3)**
Time to Next Hatching	Day 490	Day 490	Day 490
Desired Fish Weight	4.5Kg	3.8Kg	4.5Kg
Smolt Size	250g	250g	500g
Smolt Introduction to Sea	Day 239	Day 239	Day 279
Harvesting on	Day 650	Day 616	Day 641
Total Production Time	411 Days	377 Days	362 Days

The experiment (Table: 10) is run based on the 500 grams smolt to check whether and how the policy can create incentives. Desired weight is set to 4.5Kg. Smolt is introduced to the sea on the day 279 and harvested on day 641. It takes 377 days or little more than 12 months to complete a production cycle that is approximately 2 months saving in a production cycle. To keep the smolt flow continuous, “time for next hatching” is set to the day 490. Policy outcomes are discussed below

Experiment outcomes

The experiment is run to observe the potential benefit of using larger smolts in terms of production duration, resource utilization, lice infestation and gross profit. By running the experiment significant changes are observed on the key parameters. Observed outcomes are discussed below.

Table 11: Experiment outcomes for policy 2.			
Parameter	**Base Run (Run 1)**	**Policy 1 (Run 2)**	**Policy 2(Run 3)**
Production Duration	14Months	13Months	12Months
Total MTB Utilization	60%	60%	65%
Total Slaughtered Weight	17M KG	17M KG	19.4M KG
Total Operating Expenses	715M NOK	689M NOK	749M NOK
Total Feed Cost	448M NOK	428M NOK	400M NOK
Total Treatment Cost	13.2M NOK	9.12M NOK	2.07M NOK
Gross Profit	76.7M	127M	166M
Production Cost for 1Kg Fish	42NOK	40.5NOK	38.5NOK

Table 11 presents, the policy 2 experiment results that are discussed elaborately below.

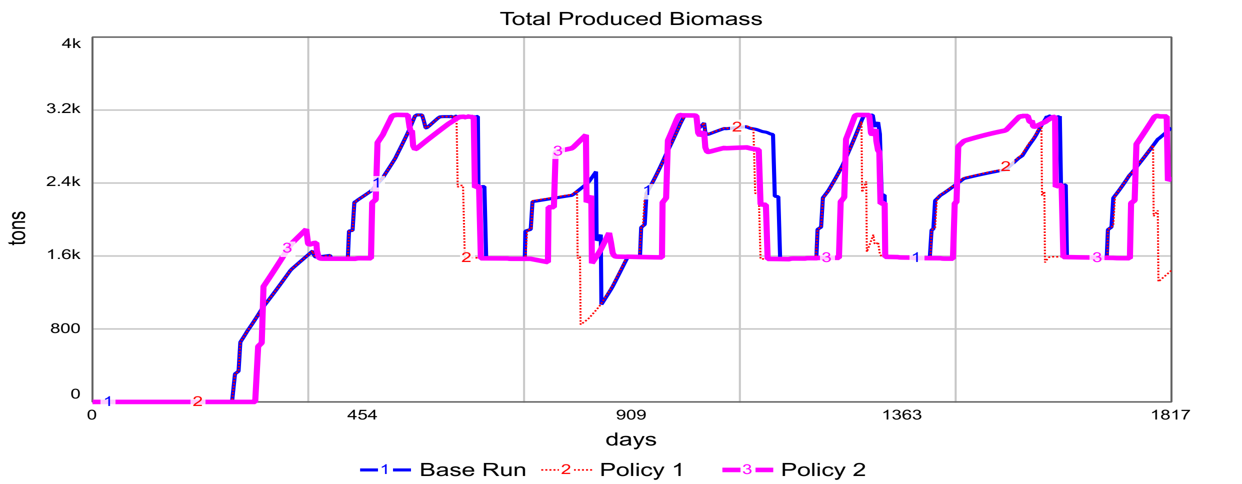


Figure 66: Total MTB utilization comparison between reference mode, policy 1 and policy 2 outcomes.

Policy outcome ensures increased MTB utilization in Figure: 57. By adopting the policy, production time is reduced by approximately 2 months that lift up the MTB utilization by 5%. Improved capacity utilization certainly enhances production yield considerably.

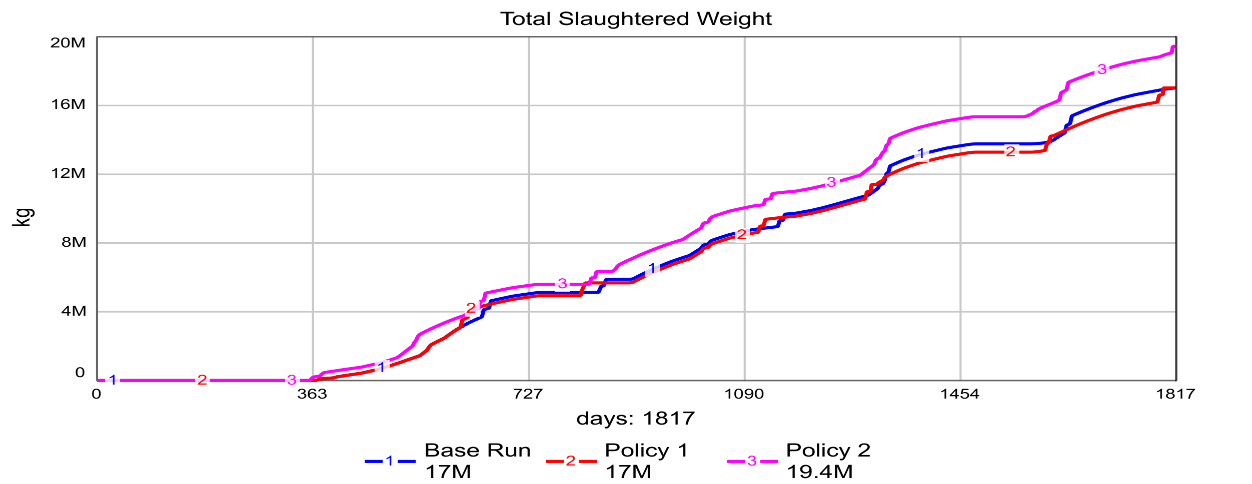


Figure 67: Total slaughtered weight comparison between current production model policy 1and policy 2 outcomes.

However, increasing MTB utilization increases total slaughtered weight by 14% comparing to the current volume. Figure:58 illustrates 2.4 million kg increase in slaughtered weight, which helps to drop the production cost significantly.

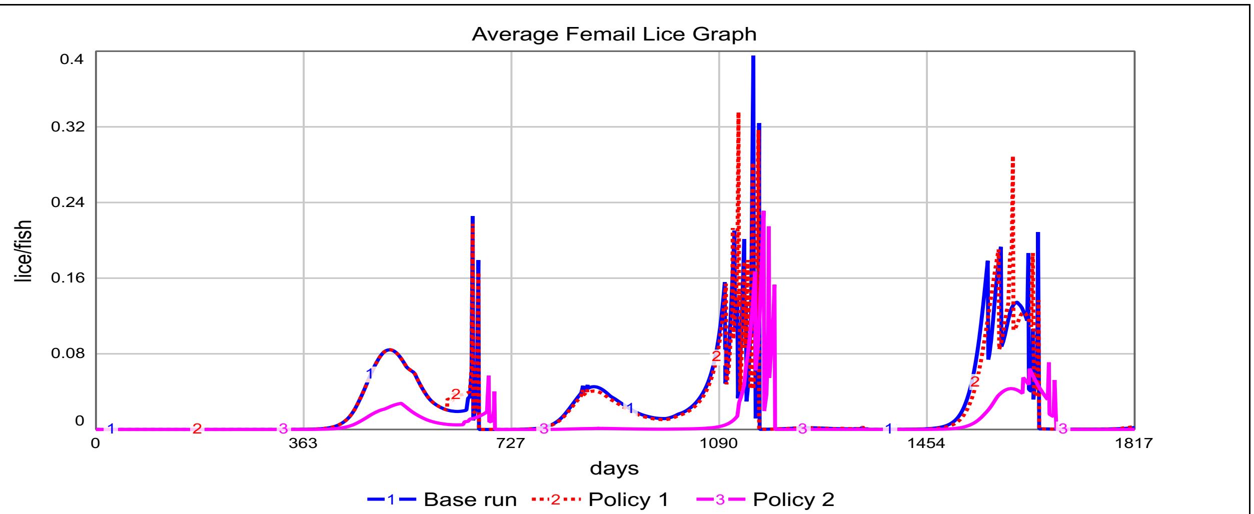


Figure 68: Average female lice infestation comparison between the current production model, policy 1 and policy 2 model.

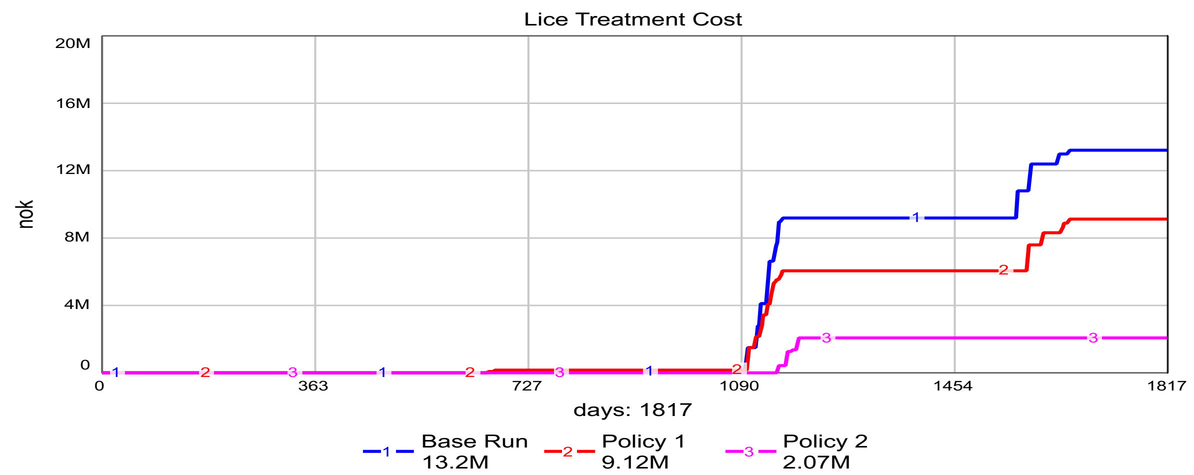


Figure 69: Lice treatment cost comparison between the current production model Policy 1 and policy 2 model.

Introducing larger smolts ensures shorter production cycle that gives rise to the benefits of less exposure to sea lice and treatment. Potential shorter exposure to sea lice is evident in figure: 59. Due to production time reduction, sea lice have shorter time to accumulate before a site is emptied and infected fish is harvested instead of receiving treatments, as the fish reaches to desire harvesting weight. As a result the policy is managed to reduce the treatment cost by 80% comparing to the current treatment cost (Figure: 60).

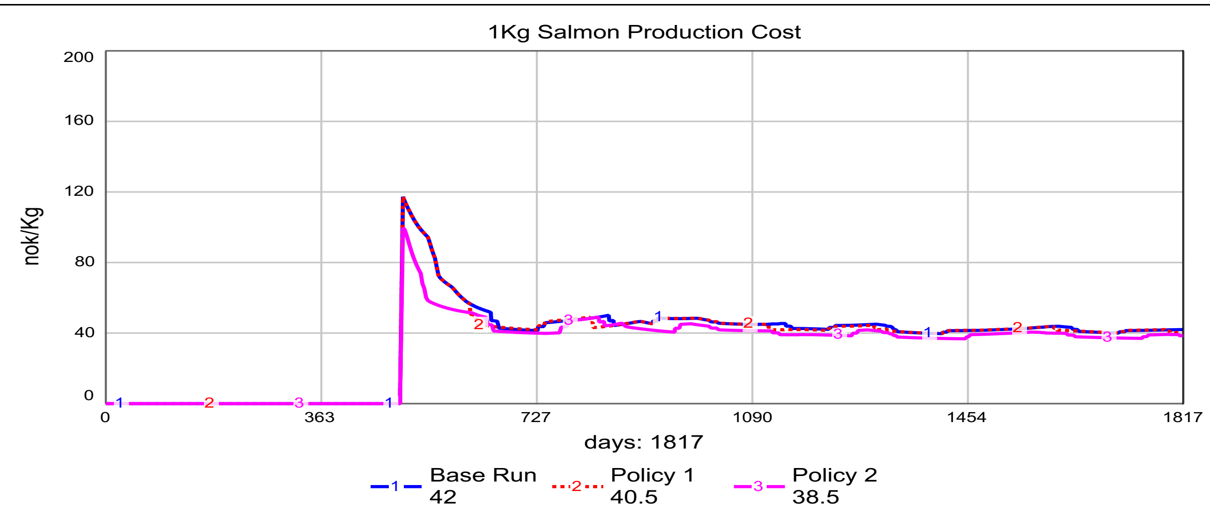


Figure 70: Per Kg salmon production cost comparison between reference mode, policy 1 and policy 2 model.

Adopted policy increases the MTB utilization by 5% and produced biomass by 14%. On the other hand lice treatment cost is reduced by 80% due to the shorter production cycles. Increasing production quantity and significantly reduced treatment cost is managed to save the total operating expenses by 5%. As a result, increased production volumes are distributed over the total operating cost that helps to reduce the "per kg production cost" by 8% (Figure: 61).

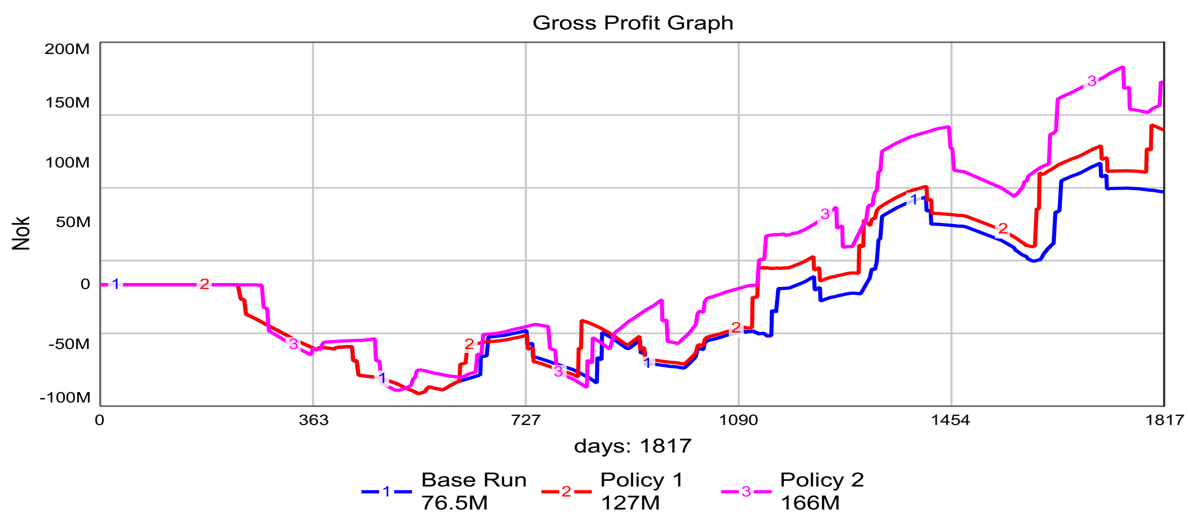


Figure 71: Gross profit comparison between reference mode, policy 1 and policy 2 model.

Moreover, introducing larger smolts ensures shorter production cycles and less exposure to the sea lice that help to raise production volume by 14% and reduce lice treatment cost by 80%. By improving production quantity and saving significant amount of treatment cost the policy is managed to lower the direct operation cost by 5%. Thus, the policy helps to elevate the gross profit by 116% comparing to the current profit (Figure: 62).

Policy 2 summary

The experiment demonstrates, using larger smolts can ensure rise in MTB utilization by 5% and overcome some of the challenges imposed by longer growth cycles. For instance lower female lice infestation reduces treatment cost by 80%. Potential benefit of using larger smolts is approximately 2 months shorter production cycle that enables farmers to maintain a stable production by increasing the yield by 14%. This increasing yield has not only the ability to generate additional revenue but also the possibility to distribute costs over a larger production quantity. Large production quantity reduces 8% cost on per Kg salmon produce. Moreover the policy demonstrates the significant ability to elevate the profitability. Considering all the facts the policy looks very strong to eliminate current challenges and make the business profitable.

Policy 3: Combining Larger Smolt and Optimal Harvesting Weight

It has been observed from the previous experiments that Introducing larger smolts and optimal harvesting weight can reduce production duration and make space available for new fish. This is an important aspect since MTB capacity is limited in a fish farm due to environmental consideration, available facilities or regulations (Asche & Bjørndal, The Economics of Salmon Aquaculture, 2011). As Figure:53 illustrates growth slows down and the marginal value decreases over time, early harvesting can make room for new smolts that may grow faster and elevate production yield. So far, previous policy results have supported the core ideas to reduce the production cycle, improve the capacity utilization, increase the production turnover and elevate the profitability. However, limited flourishing scope of an individual policy creates an intuition towards a coupling experiment to observe whether and how the benefits of large smolts and short production cycles may create economic incentives in production cost. To satisfy that curiosity a joint policy analysis is conducted and discussed below.

Table 12: Experiment parameter setting for testing policy 3.

Variable	**Base Run (Run 1)**	**Policy 1 (Run 2)**	**Policy 2 (Run 3)**	**Policy3 (Run 4)**
Time to Next Hatching	Day 490	Day 490	Day 490	Day 385
Desired Fish Weight	4.5Kg	3.8Kg	4.5Kg	3.8Kg
Smolt Size	250g	250g	500g	500g
Smolt Introduction to Sea	Day 239	Day 239	Day 279	Day 279
Harvesting on	Day 650	Day 616	Day 641	Day 578
Total Production Time	411 Days	377 Days	362 Days	299 Days

The experiment (Table: 12) is run combining the larger smolts (500 grams) and lower weight class (between 3.5Kg to 4Kg) to observe whether and how the policy can create incentives for the fish farm. Smolt is introduced to the sea on the day 279 and harvested on day 578. It takes 299 days or little more than 10 months to complete a production cycle, which is approximately 4 months saving in a production cycle. To ensure the smolts availability, "time for next hatching" is set to day 385. Policy outcomes are discussed below

Experiment outcomes

The experiment is run to observe the potential benefit of using larger smolts and lower harvesting weight in terms of production duration, MTB utilization, lice infestation and gross profit. The experiment demonstrates remarkable outcomes on the key parameters. Outcomes are discussed below.

Table 13: Experiment outcomes for policy 3.

Parameter	Base Run (Run 1)	Policy 1 (Run 2)	Policy 2 (Run 3)	Policy 3 (Run 4)
Production Duration	14Months	13Months	12Months	10Months
Total MTB Utilization	60%	60%	65%	72%
Total Slaughtered Weight	17M KG	17M KG	19.4M KG	22.6M KG
Total Operating Expenses	715M NOK	689M NOK	749M NOK	853M NOK
Total Feed Cost	448M NOK	428M NOK	400M NOK	445M NOK
Total Treatment Cost	13.2M NOK	9.12M NOK	2.07M NOK	18.3M NOK
Gross Profit	76.7M	127M	166M	197M
Production Cost for 1Kg Fish	42NOK	40.5NOK	38.5NOK	37.6NOK

Table 13 presents, the policy 3 experiment results that are discussed in detail below.

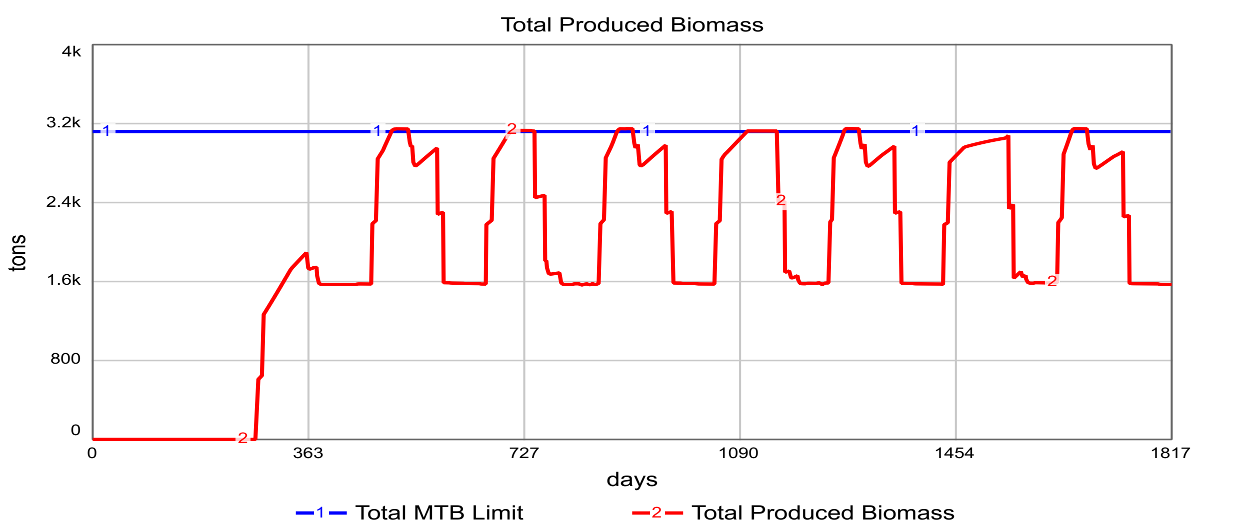


Figure 72: Total MTB utilization illustration between the total MTB limit and total produced biomass by adopting policy 3.

As the MTB is considered the most scarce and expensive resource for the fish farm operation so efficient MTB usage ensures sustainable profitability. When it comes to MTB utilization, permission with an MTB of 3120 tons can contain about 600000 fish of 5kg each at a time. Whereas using the same capacity, over a million 3kg fish can be produced, which is approximately 60% more production quantity. From that perspective MTB utilization reaches to the optimum level by using larger smolts and smaller weight class (between 3kg-to 4kg). Figure:63 illustrates, by adopting the policy MTB utilization reaches around 72% from the current 60% utilization that ensures almost 12% more capacity utilization.

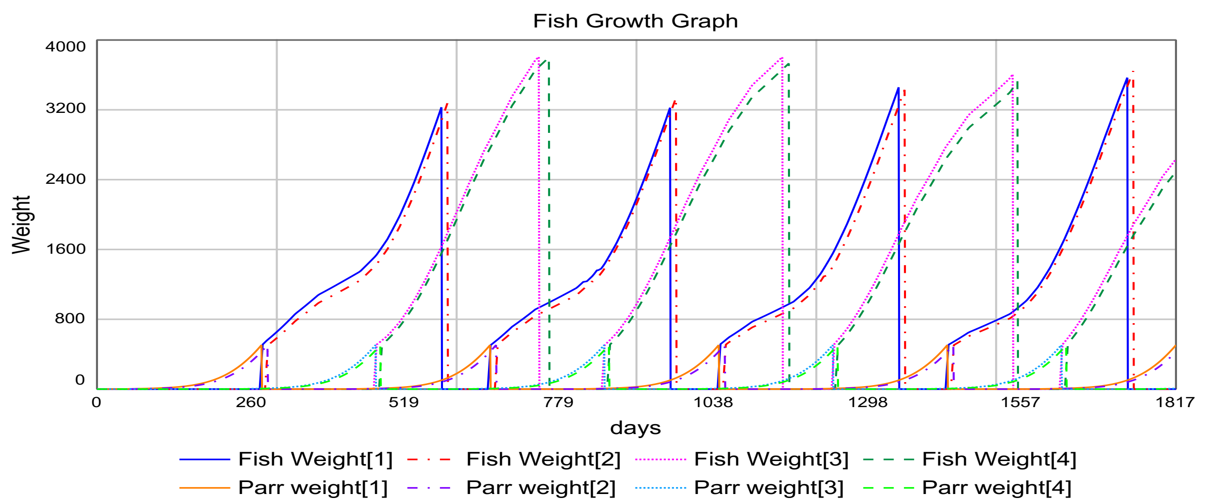


Figure 73: Illustration of increased production cycle during the simulation period (5 years) by adopting policy 3.

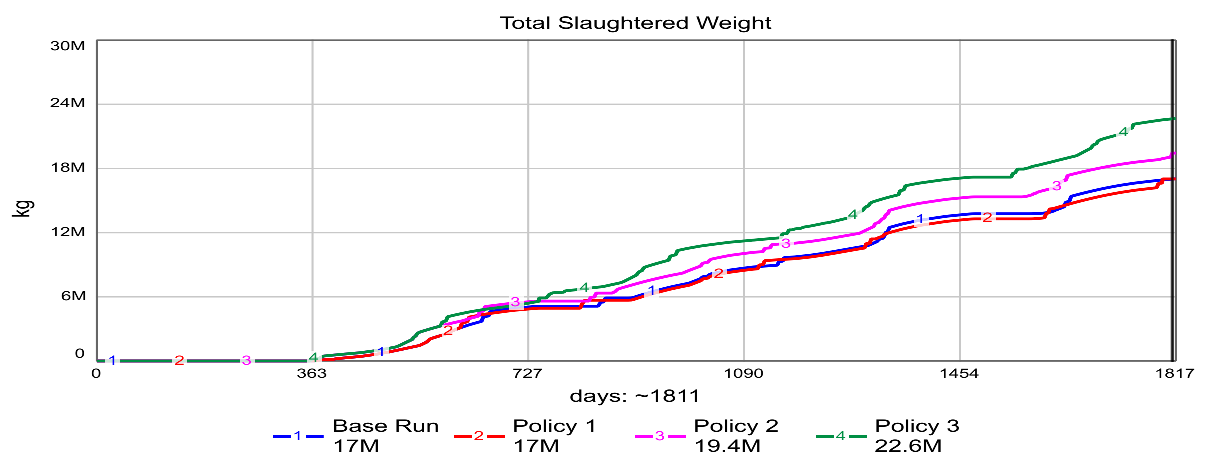


Figure 74: Total slaughtered weight comparison between current production model policy 1, policy 2 and policy 3 outcomes.

Introducing larger smolts and lower weight class, production cycle is four months shorter than the traditional production cycle. Figure:64 illustrates, elimination of several months per production cycle includes an extra production cycle during the same time frame. Including an extra production cycle increases total slaughtered weight volume to 22.8 million (Figure: 65) that is 33% more than the tradition slaughtered weight.

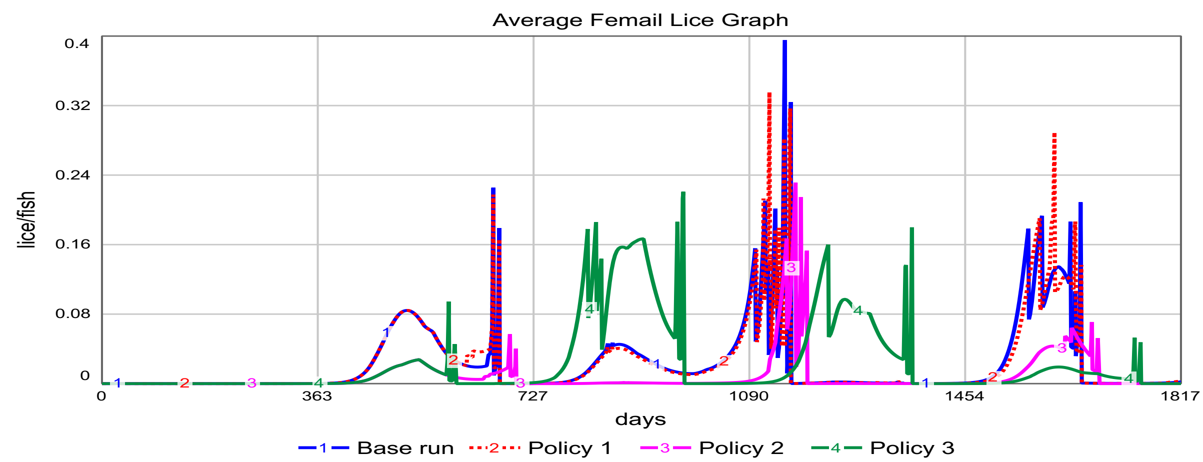


Figure 75: Average female lice infestation comparison between the current production model, policy 1, policy 2 and policy 3 model.

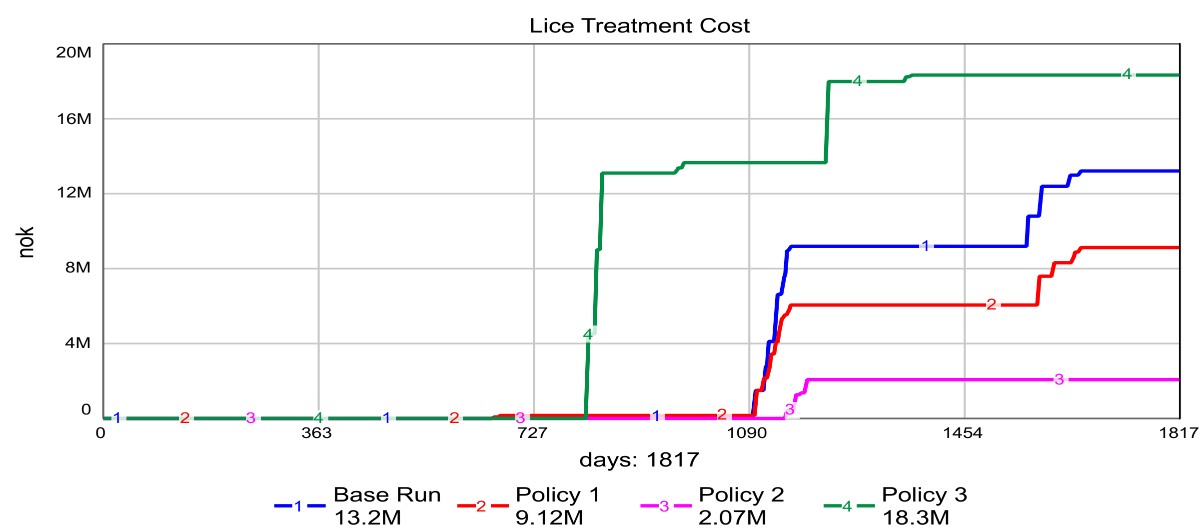


Figure 76: Lice treatment cost comparison between the current production model, Policy 1, policy 2 and policy 3 model.

Figure:66 shows increased production volume increases the lice infestation that makes the treatment cost 38% higher comparing to the current treatment cost. Since the policy increases MTB utilization from the beginning, female lice growth is increased during biomass reaches to the maximum level. Then the treatment starts well ahead to control those lice. Thus, the treatment cost is increased by 38% (Figure: 67). However the production volume compensates the additionally incurred treatment cost.

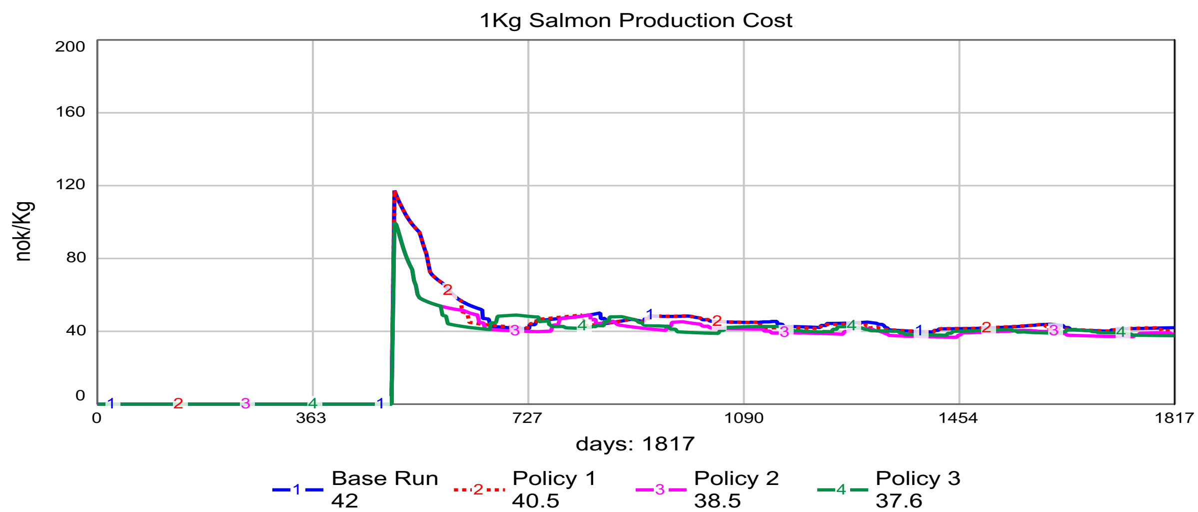


Figure 77: Per Kg salmon production cost comparison between reference mode, policy 1, policy 2 and policy 3 model.

Figure:68 illustrates 10% drop in per kg production cost by adopting the policy comparing to the current production cost. The potential savings in per kg production cost is achieved due to the distribution of larger production volume over the direct production cost. An "economies of scale" is realized from the policy. As can be seen from the result feed cost, which contains a substantial share of production cost is managed to control by 1% comparing to the current feed cost, even after significant rise in production volume.

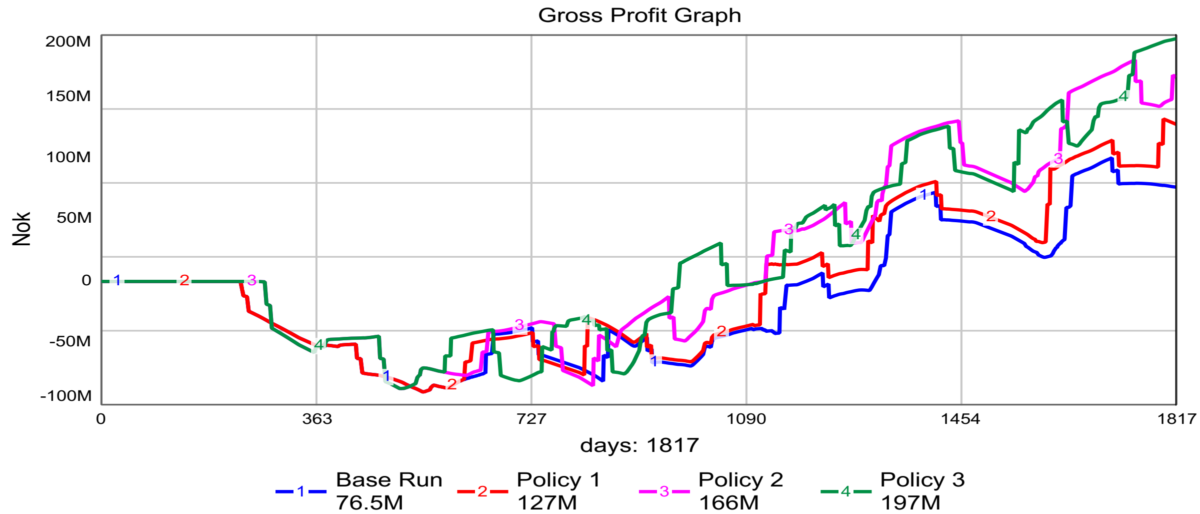


Figure 78: Gross profit comparison between reference mode, policy 1, policy 2 and policy 3 model.

Moreover, the policy shows remarkable improvements in the gross profit. Figure:69 illustrates faster economic recovery comparing to the current status. Improved MTB utilization and increased volume creates "economies of scale", that elevates the gross profit by 156% at the end of the simulation.

Policy 3 summary

From the above facts and figures it is evident that introducing larger smolts and smaller weight class is not only utilizing the MTB capacity efficiently but also improving the production yield. Simulation results exhibits 72% MTB utilization that is 12% more capacity utilization comparing to the current production model. Production cycle is reduced by 4 months that increases the production volume by 33%. Yet, significant increased production quantity has managed to control the total feed cost by 1%. However, increased production volume increases operating expenses by 20%, among them lice treatment alone takes up 38%. Thus the policy seems very robust reducing production time, improving capacity utilization and increasing production quantity to ensure "economies of scale".

Summary of Different Policy Analysis

Table 14: Results for different policy analysis.

Parameter	Base Run (Run 1)	Policy 1 (Run 2)	Policy 2 (Run 3)	Policy 3 (Run 4)	Policy 2 Outcome	Policy 3 Outcome
Production Duration	14 Months	13Months	12Months	10Months	2Months	4Months
Total MTB Utilization	60%	60%	65%	72%	5%	12%
Total Slaughtered Weight	17M KG	17M KG	19.4M KG	22.6M KG	14%	33%
Total Operating Expenses	715M NOK	689M NOK	749M NOK	853M NOK	5%	20%
Total Feed Cost	448M NOK	428M NOK	400M NOK	445M NOK	10%	1%
Total Treatment Cost	13.2M NOK	9.12M NOK	2.07M NOK	18.3M NOK	83%	38%
Gross Profit	76.7M	127M	166M	197M	116%	156%
Production Cost for 1Kg Fish	42NOK	40.5NOK	38.5NOK	37.6NOK	8%	10%

From the above experiments, it is observed (Table: 14) longer production cycle is not only limiting the MTB capacity utilization but also exposing fish to the unfavorable periods with the highest risk of sea lice infestation. The experiments exhibit smaller smolts and a longer production cycle increases the risk of losses in all phases of the cycle. With the traditional production model, poor MTB utilization and challenges with the sea lice lead to an increase in direct production cost. Whereas introducing larger smolts and smaller weight class ensure 4 months drop in the production cycle, that gives rise to the benefits of 72% MTB utilization, less exposure to sea lice and higher production turnover.

However, the expected policy outcome depends on the policy implementation willingness and efficiencies. The analysis reveals individual policy has its limit to grow but combinations of policies have often exceeded that threshold to thrive. In this study, all the policies are able to reduce the production cycle fairly short. First policy improves profitability due to the effect of the marginal relative market price between the weight classes. On the other hand, second policy expands the profitability by improving MTB utilization by 5% and reducing lice treatment cost by 80%. Yet, coupling the policies have exceeded the individual threshold, that observes encouraging outcomes through a drop of production time by 4 months, MTB utilization by 72% and an increase in production volume by 33%. Perhaps the policy creates an "economies of scale". However, alteration in one part often adversely reacts to the other parts of the system. These policies are also not out of that scope. By keeping production cycle shorter and improving capacity utilization, production intensity increases that leads to an increase in lice infestation and creates uncertainty related to the water quality of the location. Therefore, the opportunity cost of these policies might be serious in the long run. To understand the potential environmental impacts, possibly an extensive comparative ecological-economic analysis are required to conduct.

5. CONCLUSIONS

The result of this study shows that the existing production model of the fish farms is making the profit, despite having idle capacity, lower production quantity, strictly imposed regulations, fish health, lice problem and environmental uncertainties. However, introducing larger smolts and smaller harvesting weight class, the production cycle is reduced by 4 months. The shorter production cycle shows significant impacts on MTB utilization, production volume and lice infestation. Coupling effect of the policies elevates the MTB utilization efficiency by 12%, production yield by 33% and profitability by 156%. Adopting the policy, an extra production cycle is included by eliminating several months from the entire production period. Moreover, increased production turnover ensures “economies of scale”. Thus, suggested joint policy indicates better resource management, increased production volume, healthy fish, and improved economic growth. Yet, this leads to an uncertainty related to the lice infestation and water quality of the production location due to increase in production intensity. Thus, an extensive environmental analysis is required to understand the potential environmental impacts and overall sustainability in the long run.

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APPENDIX

Appendix A – Equations –Production and Growth Sector

Juvenile Growth Sector

Equations and Comments	Unit
Death_Rate = 20	Fish per day
Desired_Smolt_weight[1] = 250 Desired_Smolt_weight[2] = 250 Desired_Smolt_weight[3] = 250 Desired_Smolt_weight[4] = 250	Grams
First_hatching = 0	Days
Second_hatching = 10	Days
Third_Hatching = 192	Days
Fourth_Hatching = 200	Days
Time_to_next = 470	Days
Fry_0g_to_10g[1](t) = Fry_0g_to_10g[1](t - dt) + (Fish_egg_Hatching[1]-Moving_to_Room_1[1] - Death_Rate_Fry[1]) * dt INIT Fry_0g_to_10g[1] = 0 Fry_0g_to_10g[2](t) = Fry_0g_to_10g[2](t - dt) + (Fish_egg_Hatching[2]-Moving_to_Room_1[2] - Death_Rate_Fry[2]) * dt INIT Fry_0g_to_10g[2] = 0 Fry_0g_to_10g[3](t) = Fry_0g_to_10g[3](t - dt) + (Fish_egg_Hatching[3] - Moving_to_Room_1[3] - Death_Rate_Fry[3]) * dt INIT Fry_0g_to_10g[3] = 0 Fry_0g_to_10g[4](t) = Fry_0g_to_10g[4](t - dt) + (Fish_egg_Hatching[4] - Moving_to_Room_1[4] - Death_Rate_Fry[4]) * dt INIT Fry_0g_to_10g[4] = 0	Fish
Fish_egg_Hatching[1] = PULSE (Number_of_Fry_per_Cohort, First_hatching, Time_to_next) Fish_egg_Hatching[2] = PULSE (Number_of_Fry_per_Cohort, Second_hatching, Time_to_next) Fish_egg_Hatching[3] = PULSE (Number_of_Fry_per_Cohort, Third_Hatching, Time_to_next) Fish_egg_Hatching[4] = PULSE (Number_of_Fry_per_Cohort, Fourth_Hatching, Time_to_next)	Fish per day
Moving_to_Room_1[Cohorts] = IF Parr_weight >= 10 THEN PULSE (Fry_0g_to_10g-Death_Rate_Fry*DT) ELSE 0	Fish per day
Death_Rate_Fry[Cohorts] = IF Fry_0g_to_10g > 0 THEN Death_Rate ELSE 0	Fish per day
Number_of_Fry_per_Cohort = 1200000	Fish
Moving_to_Room_1[Cohorts] = IF Parr_weight >= 10 THEN PULSE (Fry_0g_to_10g-Death_Rate_Fry*DT) ELSE 0	Fish per day
Room_1_10g_to_60g[Cohorts](t) = Room_1_10g_to_60g[Cohorts](t - dt) +	Fish

(Moving_to_Room_1[Cohorts] - Moving_to_Room_2[Cohorts] - Death_Rate_Room_1[Cohorts]) * dt INIT Room_1_10g_to_60g[Cohorts] = 0	
Moving_to_Room_2[Cohorts] = IF Parr_weight >= 60 THEN PULSE(Room_1_10g_to_60g-Death_Rate_Room_1*DT) ELSE 0	Fish per day
Death_Rate_Room_1[Cohorts] = IF Room_1_10g_to_60g > 0 THENDeath_Rate ELSE 0	Fish per day
Room_2_60g_to_100g[Cohorts](t) = Room_2_60g_to_100g[Cohorts](t - dt) + (Moving_to_Room_2[Cohorts] - Moving_to_Room_3[Cohorts] - Death_Rate_Room_2[Cohorts]) * dt INIT Room_2_60g_to_100g[Cohorts] = 0	Fish
Moving_to_Room_2[Cohorts] = IF Parr_weight >= 60 THEN PULSE (Room_1_10g_to_60g-Death_Rate_Room_1*DT) ELSE 0	Fish per day
Moving_to_Room_3[Cohorts] = IF Parr_weight >= 100 THEN PULSE (Room_2_60g_to_100g-Death_Rate_Room_2*DT) ELSE 0	Fish per day
Death_Rate_Room_2[Cohorts] = IF Room_2_60g_to_100g > 0 THEN Death_Rate ELSE 0	Fish per day
Room_3_100g_to_500g[Cohorts](t) = Room_3_100g_to_500g[Cohorts](t - dt) + (Moving_to_Room_3[Cohorts] - To_Sea[Cohorts, Location] - Death_Rate_Room_3[Cohorts]) * dt INIT Room_3_100g_to_500g[Cohorts] = 0	Fish
Moving_to_Room_3[Cohorts] = IF Parr_weight >= 100 THEN PULSE (Room_2_60g_to_100g-Death_Rate_Room_2*DT) ELSE 0	Fish per day
To_Sea[Cohorts, Location] --> Sea_and_Slaughter_Sector: Death_Rate_Room_3[Cohorts] = IF Room_3_100g_to_500g > 0 THEN Death_Rate ELSE 0	Fish per day

Juvenile Feeding Sector

Equations and Comments	**Unit**
"%_of_weight_fed_at_7c"[Cohorts] = GRAPH(Parr_weight) (0.0, 3.312), (1.0, 2.783), (5.0, 1.16445), (15.0, 1.2535), (30.0, 1.4835),(100.0, 1.4375), (200.0, 1.3225), (300.0, 1.219), (400.0, 1.1155), (500.0,1.035) *Graphs for all of the "% of weight fed at Xc" converters created using tablesfrom Skretting AS, document provided by Osland Havbruk*	Per day
"%_of_weight_fed_at_8c"[Cohorts] = GRAPH(Parr_weight) (0.0, 3.7835), (1.0, 3.174), (5.0, 1.886), (15.0, 1.4375), (30.0, 1.7135), (100.0,1.656), (200.0, 1.518), (300.0, 1.3915), (400.0, 1.288), (500.0, 1.196)	Per day
"%_of_weight_fed_at_9c"[Cohorts] = GRAPH(Parr_weight) (0.0, 4.255), (1.0, 3.5765), (5.0, 2.1275), (15.0, 1.6215), (30.0, 1.9435),(100.0, 1.863), (200.0, 1.7135), (300.0, 1.564), (400.0, 1.4375), (500.0,1.334)	Per day
"%_of_weight_fed_at_10c"[Cohorts] = GRAPH(Parr_weight) (0.0, 4.7265), (1.0, 3.9675), (5.0, 2.369), (15.0, 1.8055), (30.0, 2.1735),(100.0, 2.585), (200.0, 1.886), (300.0, 1.7135), (400.0,1.5755), (500.0,1.4605)	Per day
"%_of_weight_fed_at_11c"[Cohorts] = GRAPH(Parr_weight) (0.0, 5.198), (1.0, 4.370), (5.0, 2.6105), (15.0, 1.9895), (30.0, 2.392), (100.0,2.2425), (200.0, 2.0355), (300.0, 1.8515), (400.0, 1.702), (500.0, 1.5755)	Per day
"%_of_weight_fed_at_12c"[Cohorts] = GRAPH(Parr_weight) (0.0, 5.681), (1.0, 4.761), (5.0, 2.852), (15.0, 2.1735), (30.0, 2.599), (100.0,2.4035),	Per day

(200.0, 2.1735), (300.0, 1.978), (400.0, 1.817), (500.0, 1.679)	
"%_of_weight_fed_at_13c"[Cohorts] = GRAPH(Parr_weight) (0.0, 6.1525), (1.0, 5.1635), (5.0, 2.37935), (15.0, 2.3575), (30.0, 2.783),(100.0, 2.5415), (200.0, 2.885), (300.0, 2.0815), (400.0,1.909), (500.0,1.771)	Per day
"%_of_weight_fed_at_14c"[Cohorts] = GRAPH(Parr_weight) (0.0, 6.624), (1.0, 5.5545), (5.0, 3.335), (15.0, 2.5415), (30.0,2.9555), (100.0,2.6565), (200.0, 2.3805), (300.0, 2.162), (400.0, 1.978), (500.0, 1.8285)	Per day
Feed_conversion_ratio_parr = 1.15	Dimensionless
Feeding_Rate_Parr[Cohorts] = IF Temperature_Parr >= 7 AND Temperature_Parr <= 7.99 THEN "%_of_weight_fed_at_7c" ELSE IF Temperature_Parr >= 8 AND Temperature_Parr <= 8.99 THEN "%_of_weight_fed_at_8c" ELSE IF Temperature_Parr >= 9 AND Temperature_Parr <= 9.99 THEN "%_of_weight_fed_at_9c" ELSE IF Temperature_Parr >= 10 AND Temperature_Parr <= 10.99 THEN "%_of_weight_fed_at_10c" ELSE IF Temperature_Parr >= 11 AND Temperature_Parr <= 11.99 THEN "%_of_weight_fed_at_11c" ELSE IF Temperature_Parr >= 12 AND Temperature_Parr <= 12.99 THEN "%_of_weight_fed_at_12c" ELSE IF Temperature_Parr >= 13 AND Temperature_Parr <= 13.99 THEN "%_of_weight_fed_at_13c" ELSE IF Temperature_Parr >= 14 AND Temperature_Parr <= 14.99 THEN "%_of_weight_fed_at_14c" ELSE 1 *Feeding rate chooses the percentage of body weight fed to the fish per daybased on the temperature and the size of the fish.*	Dimensionless per day
Initial_Fry_weight = 0.2	Grams
Parr_weight[Cohorts](t) = Parr_weight[Cohorts](t - dt) + (Parr_Weight_Gain[Cohorts]) * dt INIT Parr_weight[Cohorts] = Initial_Fry_weight	Grams
Parr_Weight_Gain[Cohorts] = IF To_Sea[Cohorts,1]> 0 OR To_Sea[Cohorts,2]> 0 OR To_Sea[Cohorts,3]> 0 OR To_Sea[Cohorts,4]> 0 THEN (-Parr_weight+Initial_Fry_weight)/DT ELSE Amount_of_parr_food_per_day/Feed_conversion_ratio_parr *This formula includes a condition to reset the parr weight gain when thecohort has left the juvenile growth sector*	Grams/Day
Temperature_Parr = 14	Degrees C
Total_Amount_of_parr_Food[Cohorts](t) = Total_Amount_of_parr_Food[Cohorts](t - dt) + (Amount_of_parr_food_per_day[Cohorts]) * dt INIT Total_Amount_of_parr_Food[Cohorts] = 0	Grams
Amount_of_parr_food_per_day[Cohorts] = IF Fry_0g_to_10g > 0 OR Room_1_10g_to_60g > 0 OR Room_2_60g_to_100g > 0 OR Room_3_100g_to_500g > 0 THEN (Feeding_Rate_Parr/100)*Parr_weight ELSE 0 *This formula includes a condition that there must be parr in the rooms inorder for them to be fed*	Grams per day

Fish Feeding Sector

Equations and Comments	**Unit**
"%_of_weight_fed_at_4c_1"[Cohorts] = GRAPH(Fish_Weight) (30, 0.805), (100, 0.7705), (200, 0.713), (300, 0.6555), (400, 0.598), (500,0.552), (600, 0.5175), (700, 0.483), (800, 0.4485), (900, 0.4255), (1000,0.4025), (1100, 0.3795),	Per day

(1200, 0.368), (1300, 0.345), (1400, 0.3335), (1500,0.322), (1600, 0.3105), (1700, 0.299), (1800, 0.2875), (1900, 0.276), (2000,0.276), (2250, 0.253), (2500, 0.2415), (2750, 0.230), (3000, 0.2185), (3250,0.207), (3500, 0.207), (3750, 0.1955), (4000, 0.1955), (4250, 0.184), (4500,0.184), (4750, 0.1725), (5000, 0.1725), (7000, 0.1725) *Graphs for all of the "% of weight fed at Xc" converters created using tablesfrom Skretting AS, document provided by Osland Havbruk*	
"%_of_weight_fed_at_6c_1"[Cohorts] = GRAPH(Fish_Weight) (30, 1.2535), (100, 1.219), (200, 1.127), (300, 1.035), (400, 0.9545), (500,0.8855), (600, 0.8165), (700, 0.7705), (800, 0.7245), (900, 0.690), (1000,0.6555), (1100, 0.621), (1200, 0.598), (1300, 0.575), (1400, 0.552), (1500,0.529), (1600, 0.5175), (1700, 0.4945), (1800, 0.483), (1900, 0.4715), (2000,0.460), (2250, 0.4255), (2500, 0.4025), (2750, 0.3795), (3000, 0.368), (3250,0.3565), (3500,0.345), (3750, 0.3335), (4000, 0.322), (4250, 0.3105), (4500,0.3105), (4750, 0.299), (5000, 0.299), (7000, 0.2875)	Per day
"%_of_weight_fed_at_8c_1"[Cohorts] = GRAPH(Fish_Weight) (30, 1.7135), (100, 1.656), (200, 1.518), (300, 1.3915), (400, 1.288), (500,1.196), (600, 1.1155), (700, 1.0465), (800, 0.989), (900, 0.9315), (1000,0.8855), (1100, 0.851), (1200, 0.8165), (1300,0.782), (1400, 0.7475), (1500,0.7245), (1600, 0.7015), (1700,0.6785), (1800, 0.6555), (1900, 0.644),(2000, 0.621), (2250,0.5865), (2500, 0.552), (2750, 0.529), (3000, 0.506),(3250, 0.483), (3500, 0.4715), (3750, 0.460), (4000, 0.437), (4250, 0.4255),(4500, 0.4255), (4750, 0.414), (5000, 0.4025), (7000, 0.391)	Per day
"%_of_weight_fed_at_10c_1"[Cohorts] = GRAPH(Fish_Weight)(30, 2.1735), (100, 2.0585), (200, 1.886), (300, 1.7135), (400, 1.5755), (500,1.4605), (600, 1.3685), (700, 1.288), (800, 1.2075), (900, 1.150), (1000,1.0925), (1100, 1.0465), (1200, 1.0005), (1300, 0.966), (1400, 0.920), (1500,0.897), (1600, 0.8625), (1700, 0.8395), (1800, 0.8165), (1900, 0.7935),2000, 0.7705), (2250, 0.7245), (2500, 0.6785), (2750, 0.644), (3000, 0.621),(3250, 0.598), (3500, 0.575), (3750, 0.552), (4000, 0.5405), (4250, 0.5175),(4500, 0.506), (4750, 0.4945), (5000, 0.483), (7000, 0.483)	Per day
"%_of_weight_fed_at_12c_1"[Cohorts] = GRAPH(Fish_Weight)(30, 2.599), (100, 2.4035), (200, 2.1735), (300, 1.978), (400, 1.817), (500,1.679), (600, 1.564), (700, 1.472), (800, 1.3915), (900, 1.311), (1000,1.2535), (1100, 1.196), (1200, 1.150), (1300, 1.104), (1400, 1.058), (1500,1.0235), (1600, 0.989), (1700, 0.9545), (1800, 0.920), (1900, 0.897), (2000,0.874), (2250, 0.8165), (2500, 0.7705), (2750, 0.736), (3000, 0.7015), (3250, 0.667), (3500, 0.644), (3750, 0.621), (4000, 0.598), (4250, 0.5865), (4500,0.5635), (4750, 0.552), (5000, 0.5405), (7000, 0.529)	Per day
"%_of_weight_fed_at_14c_1"[Cohorts] = GRAPH(Fish_Weight)(30, 2.9555), (100, 2.6565), (200, 2.3805), (300, 2.162), (400, 1.978), (500,1.8285), (600, 1.702), (700, 1.5985), (800, 1.5065), (900, 1.426), (1000,1.357), (1100, 1.288), (1200, 1.2305), (1300, 1.1845), (1400, 1.1385), (1500,1.0925), (1600, 1.058), (1700, 1.0235), (1800, 0.989), (1900, 0.966), (2000, 0.9315), (2250, 0.874), (2500, 0.828), (2750, 0.782), (3000, 0.736), (3250,0.713), (3500, 0.6785), (3750, 0.6555), (4000, 0.6325), (4250, 0.6095),(4500, 0.598), (4750, 0.575), (5000, 0.5635), (7000, 0.552)	Per day
Feed_conversion_ratio_fish = 1.15	Dimensionless
feeding_rate_fish[Cohorts] = IF Temperature >= 4 AND Temperature <= 6 THEN "%_of_weight_fed_at_4c_1" ELSE IF Temperature >= 6 AND Temperature <= 8 THEN "%_of_weight_fed_at_6c_1" ELSE IF Temperature>= 8 AND Temperature <= 10 THEN "%_of_weight_fed_at_8c_1" ELSE IF Temperature >= 10 AND Temperature <= 12 THEN "%_of_weight_fed_at_10c_1" ELSE IF Temperature >= 12 AND Temperature <= 14 THEN "%_of_weight_fed_at_12c_1" ELSE IF Temperature >= 14 AND Temperature <= 16 THEN "%_of_weight_fed_at_14c_1" ELSE 1	Per day

The feeding rate chooses the percentage of body weight fed to the fish per daybased on the temperature and the size of the fish.	
Historical_temperature = GRAPH(TIME) (0, 6.20), (31, 5.40), (59, 5.30), (90, 6.50), (120, 9.70), (151, 12.60), (181,15.20), (212, 15.50), (243, 13.50), (273, 10.90), (304, 8.70), (334, 8.00), (365,6.20), (396, 5.40), (424, 5.30), (455, 6.50), (485, 9.70), (516, 12.60), (546,15.20), (577, 15.50), (608, 13.50), (638, 10.90), (669, 8.70), (699, 8.00), (730,6.20), (761, 5.40), (789, 5.30), (820, 6.50), (850, 9.70), (881, 12.60), (911,15.20), (942, 15.50), (973, 13.50), (1003, 10.90), (1034, 8.70), (1064, 8.00),(1095, 6.20), (1126, 5.40), (1154, 5.30), (1185, 6.50), (1215, 9.70), (1246,12.60), (1276, 15.20), (1307, 15.50), (1338, 13.50), (1368, 10.90), (1399, 8.70), (1429, 8.00), (1460, 6.20), (1491, 5.40), (1519, 5.30), (1550, 6.50),(1580, 9.70), (1611, 12.60), (1641, 15.20), (1672, 15.50), (1703, 13.50),(1733, 10.90), (1764, 8.70), (1794, 8.00), (1825, 6.20) *The ghost variable "temperature" in the fish feeding sector is the same as the historical temperature above*	Degrees C
Fish_Weight[Cohorts](t) = Fish_Weight[Cohorts](t - dt) + (Fish_Weight_Gain[Cohorts]) * dt Fish_Weight[Cohorts] = 0	Grams
Fish_Weight_Gain[1] = IF To_Sea[1,1] > 0 THEN (Parr_weight[1])/DT ELSE IF Weight_Slaughter[1] > 0 THEN (-Fish_Weight[1]/DT) ELSE Amount_of_fish_food_per_day/Feed_conversion_ratio_fish Fish_Weight_Gain[2] = IF To_Sea[2,2] > 0 THEN Parr_weight[2]/DT ELSE IF Weight_Slaughter[2] > 0 THEN (-Fish_Weight[2]/DT) ELSE Amount_of_fish_food_per_day/Feed_conversion_ratio_fish Fish_Weight_Gain[3] = IF To_Sea[3,3] > 0 THEN Parr_weight[3]/DT ELSE IF Weight_Slaughter[3] > 0 THEN (-Fish_Weight[3]/DT) ELSE Amount_of_fish_food_per_day/Feed_conversion_ratio_fish Fish_Weight_Gain[4] = IF To_Sea[4,4] > 0 THEN Parr_weight[4]/DT ELSE IF Weight_Slaughter[4] > 0 THEN (-Fish_Weight[4]/DT) ELSE Amount_of_fish_food_per_day/Feed_conversion_ratio_fish *These formulas include a condition that there must be fish in the locations inorder to be fed, and also resets the fish weight once the fish have left thelocation*	Grams per day
Total_Amount_of_Fish_Food[Cohorts](t) = Total_Amount_of_Fish_Food[Cohorts](t - dt) + (Amount_of_fish_food_per_day[Cohorts]) * dt INIT Total_Amount_of_Fish_Food[Cohorts] = 0	Grams
Amount_of_fish_food_per_day[1] = IF Locations[1] >100 AND Time_with_no_feeding_due_to_treatment[1] = 0 THEN feeding_rate_fish/100*Fish_Weight ELSE 0 Amount_of_fish_food_per_day[2] = IF Locations[2] >100 AND Time_with_no_feeding_due_to_treatment[2] = 0 THEN feeding_rate_fish/100*Fish_Weight ELSE 0 Amount_of_fish_food_per_day[3] = IF Locations[3] >100 AND Time_with_no_feeding_due_to_treatment[3] = 0 THEN feeding_rate_fish/100*Fish_Weight ELSE 0 Amount_of_fish_food_per_day[4] = IF Locations[4] >100 AND Time_with_no_feeding_due_to_treatment[4] = 0 THEN feeding_rate_fish/100*Fish_Weight ELSE 0 *This equation includes a condition that fish must be in the location in order tobe fed, and must not be undergoing treatment for lice.*	Grams per day

Sea and Slaughter Sector

Equations and Comments	Units
Avg_lifespan_in_sea[1] = Normal_Life_in_sea-(Treatments_used[1]*Eff_of_treatments_on_mortality) Avg_lifespan_in_sea[2] = Normal_Life_in_sea-(Treatments_used[2]*Eff_of_treatments_on_mortality) Avg_lifespan_in_sea[3] = Normal_Life_in_sea-(Treatments_used[3]*Eff_of_treatments_on_mortality) Avg_lifespan_in_sea[4] = Normal_Life_in_sea-(Treatments_used[4]*Eff_of_treatments_on_mortality) Biomass_per_location_check[1] = IF Location_Biomass[1] > Maximum_biomass_per_location THEN 1 ELSE 0 Biomass_per_location_check[2] = IF Location_Biomass[2] > Maximum_biomass_per_location THEN 1 ELSE 0 Biomass_per_location_check[3] = IF Location_Biomass[3] > Maximum_biomass_per_location THEN 1 ELSE 0 Biomass_per_location_check[4] = IF Location_Biomass[4] > Maximum_biomass_per_location THEN 1 ELSE 0	Tons
Desired_Fish_Weight = 5000	Grams
Fallowing_period = 60	Days
Grams_per_ton = 1000000	Grams/tons*fish
Last_Slaughter_time[Location](t) = Last_Slaughter_time[Location](t - dt) + (cLST[Location]) * dt INIT Last_Slaughter_time[Location] = 0 *This stock is an imagined stock as opposed to a physical one, and accumulates thelast slaughter time for use in calculating when the location has been fallowed.*	Days
cLST[Location] = IF Time_when_Slaughter_occurs>0 THEN (Time_when_Slaughter_occurs-Last_Slaughter_time)/DT ELSE 0	Dimensio nless
Location_Biomass[1] = Locations[1]*Fish_Weight[1]/Grams_per_ton Location_Biomass[2] = Locations[2]*Fish_Weight[2]/Grams_per_ton Location_Biomass[3] = Locations[3]*Fish_Weight[3]/Grams_per_ton Location_Biomass[4] = Locations[4]*Fish_Weight[4]/Grams_per_ton	Tons
Location_MTB_Limit = 780	Tons
Locations[1](t) = Locations[1](t - dt) + (To_Sea[1, 1] + To_Sea[2, 1] + To_Sea[3, 1] + To_Sea[4, 1] - Weight_Slaughter[1] - Slaughter_based_on_Biomass[1] - Sea_based_mortality[1]) * dt INIT Locations[1] = 0 Locations[2](t) = Locations[2](t - dt) + (To_Sea[1, 2] + To_Sea[2, 2] + To_Sea[3, 2] + To_Sea[4, 2] - Weight_Slaughter[2] - Slaughter_based_on_Biomass[2] - Sea_based_mortality[2]) * dt INIT Locations[2] = 0 Locations[3](t) = Locations[3](t - dt) + (To_Sea[1, 3] + To_Sea[2, 3] + To_Sea[3, 3] + To_Sea[4, 3] - Weight_Slaughter[3] - Slaughter_based_on_Biomass[3] - Sea_based_mortality[3]) * dt INIT Locations[3] = 0 Locations[4](t) = Locations[4](t - dt) + (To_Sea[1, 4] + To_Sea[2, 4] + To_Sea[3, 4] + To_Sea[4, 4] - Weight_Slaughter[4] - Slaughter_based_on_Biomass[4] - Sea_based_mortality[4]) * dt INIT Locations[4] = 0	Fish

To_Sea[1, 1] = IF Parr_weight[1] >= Desired_Smolt_weight[1] AND Locations[1] < 100 AND TIME >= Next_introduction_Date[1] THEN PULSE (MAX (0, Room_3_100g_to_500g[1]-Death_Rate_Room_3[1]*DT),Time_when_parr_are_in_room_3[1], 20000) ELSE 0 To_Sea[2, 2] = IF Parr_weight[2] >= Desired_Smolt_weight[2] AND Locations[2] < 100 AND TIME >= Next_introduction_Date[2] THEN PULSE (MAX (0, Room_3_100g_to_500g[2]-Death_Rate_Room_3[2]*DT),Time_when_parr_are_in_room_3[2], 20000) ELSE 0 To_Sea[3, 3] = IF Parr_weight[3] >= Desired_Smolt_weight[3] AND Locations[3] < 100 AND TIME >= Next_introduction_Date[3] THEN PULSE (MAX (0, Room_3_100g_to_500g[3]-Death_Rate_Room_3[3]*DT), Time_when_parr_are_in_room_3[3], 20000) ELSE 0 To_Sea[4, 4] = IF Parr_weight[4] >= Desired_Smolt_weight[4] AND Locations[4] < 100 AND TIME >= Next_introduction_Date[4] THEN PULSE (MAX (0, Room_3_100g_to_500g[4]-Death_Rate_Room_3[4]*DT),Time_when_parr_are_in_room_3[4], 20000) ELSE 0 *These equations contain structures which ensure that all the necessary parametersare in place before fish can enter a location*	Fish per day
Weight_Slaughter[1] = IF Parr_weight[1] >= parr_weight_60_days_before_sea_introduction[1] AND Locations[1] > 10 THEN Locations[1]/Slaughter_time ELSE Slaughter_based_on_weight[1]/Slaughter_time Weight_Slaughter[2] = IF Parr_weight[2] >= parr_weight_60_days_before_sea_introduction[2] AND Locations[2] > 10 THEN Locations[2]/Slaughter_time ELSE Slaughter_based_on_weight[2]/Slaughter_time Weight_Slaughter[3] = IF Parr_weight[3] >= parr_weight_60_days_before_sea_introduction[3] AND Locations[3] > 10 THEN Locations[3]/Slaughter_time ELSE Slaughter_based_on_weight[3]/Slaughter_time Weight_Slaughter[4] = IF Parr_weight[4] >= parr_weight_60_days_before_sea_introduction[4] AND Locations[4] > 10 THEN Locations[4]/Slaughter_time ELSE Slaughter_based_on_weight[4]/Slaughter_time	Fish per day
Slaughter_based_on_Biomass[Location] = Number_of_fish_slaughtered_exceeding_biomass/Slaughter_time	Fish per day
Sea_based_mortality[1] = MAX(0, (Locations[1]/Avg_lifespan_in_sea[1])-Slaughter_based_on_Biomass[1]) Sea_based_mortality[2] = MAX(0, (Locations[2]/Avg_lifespan_in_sea[2])-Slaughter_based_on_Biomass[2]) Sea_based_mortality[3] = MAX(0, (Locations[3]/Avg_lifespan_in_sea[3])-Slaughter_based_on_Biomass[3]) Sea_based_mortality[4] = MAX(0, (Locations[4]/Avg_lifespan_in_sea[4])-Slaughter_based_on_Biomass[4])	Fish per day
Max_amount_of_tons_of_fish_in_120_cage = 381.9719	Tons per

	cage
Max_amount_of_tons_of_fish_in_160_cage = 679.750	Tons per cage
Maximum_biomass_per_location = Max_amount_of_tons_of_fish_in_120_cage*Number_of_cages_120+Max_amou nt_of_tons_of_fish_in_160_cage*Number_of_cages_160	Tons
Next_introduction_Date[Location] = IF Last_Slaughter_time > 0 THEN Last_Slaughter_time+ Fallowing_period ELSE 0	Days
Normal_Life_in_sea = 400	Days
Number_of_cages_120 = 8	Cages
Number_of_cages_160 = 0	Cages
Number_of_fish_slaughtered_exceeding_biomass[1] = IF Fish_Weight[1]> 0 THEN Slaughter_of_Exceeding_Biomass/Fish_Weight[1]*Grams_per_ton ELSE 0 Number_of_fish_slaughtered_exceeding_biomass[2] = IF Fish_Weight[2] > 0 THEN Slaughter_of_Exceeding_Biomass/Fish_Weight[2]*Grams_per_ton ELSE 0 Number_of_fish_slaughtered_exceeding_biomass[3] = IF Fish_Weight[3] > 0 THEN Slaughter_of_Exceeding_Biomass/Fish_Weight[3]*Grams_per_ton ELSE 0 Number_of_fish_slaughtered_exceeding_biomass[4] = IF Fish_Weight[4] > 0 THEN Slaughter_of_Exceeding_Biomass/Fish_Weight[4]*Grams_per_ton ELSE 0	Fish
number_of_locations = 4	Dimensionless
parr_weight_60_days_before_sea_introduction[1] = 0.2*Desired_Smolt_weight[1] parr_weight_60_days_before_sea_introduction[2] = 0.2*Desired_Smolt_weight[2] parr_weight_60_days_before_sea_introduction[3] = 0.2*Desired_Smolt_weight[3] parr_weight_60_days_before_sea_introduction[4] = 0.2*Desired_Smolt_weight[4]	Grams
Slaughter_amount_based_on_total_MTB = MAX((Total_Biomass-Total_MTB_Limit), 0)	Tons
Slaughter_amount_per_location[1] = MAX((Location_Biomass[1]-Location_MTB_Limit), 0) Slaughter_amount_per_location[2] = MAX((Location_Biomass[2]-Location_MTB_Limit), 0) Slaughter_amount_per_location[3] = MAX((Location_Biomass[3]-Location_MTB_Limit), 0) Slaughter_amount_per_location[4] = MAX((Location_Biomass[4]-Location_MTB_Limit), 0)	Tons
Slaughter_of_Exceeding_Biomass[Location] = (Slaughter_amount_based_on_total_MTB+Slaughter_amount_per_location)	Tons
Slaughter_time = 2	Days
Time_when_parr_are_in_room_3[1] = IF Room_3_100g_to_500g[1] > 194000 THEN TIME ELSE 0	Days

Time_when_parr_are_in_room_3[2] = IF Room_3_100g_to_500g[2] > 194000 THEN TIME ELSE 0 Time_when_parr_are_in_room_3[3] = IF Room_3_100g_to_500g[3] > 194000 THEN TIME ELSE 0 Time_when_parr_are_in_room_3[4] = IF Room_3_100g_to_500g[4] > 194000 THEN TIME ELSE 0	
Time_when_Slaughter_occurs[1] = IF Weight_Slaughter[1] > 0 THEN TIME ELSE 0 Time_when_Slaughter_occurs[2] = IF Weight_Slaughter[2] > 0 THEN TIME ELSE 0 Time_when_Slaughter_occurs[3] = IF Weight_Slaughter[3] > 0 THEN TIME ELSE 0 Time_when_Slaughter_occurs[4] = IF Weight_Slaughter[4] > 0 THEN TIME ELSE 0	Days
Total_Biomass = Location_Biomass[1]+Location_Biomass[2]+Location_Biomass[3]+Location_Biomass[4]	Tons
Total_MTB_Limit = Location_MTB_Limit*number_of_locations	Tons

Appendix B – Equations –Lice Sectors

Cleaner Fish Sector

Equations and Comments	**Unit**
Cleaner Fish MR = 0,028	1/days
Cleaner_fish[Location](t) = Cleaner_fish[Location](t - dt) + (Cleaner_fish_increase[Location] - Cleaner_fish_mortality[Location]) * dt	fish
INIT Cleaner_fish[Location] = 0	fish
INFLOWS: Cleaner_fish_increase[1] = IF(Locations[1]>1000) THEN PULSE(number_of_cleaner_fish_introduced[1]; Time_of_introduction; refilling_time) ELSE 0 Cleaner_fish_increase[2] = IF(Locations[2]>1000) THEN PULSE(number_of_cleaner_fish_introduced[2]; Time_of_introduction; refilling_time) ELSE 0 Cleaner_fish_increase[3] = IF(Locations[3]>1000) THEN PULSE(number_of_cleaner_fish_introduced[3]; Time_of_introduction; refilling_time) ELSE 0 Cleaner_fish_increase[4] = IF(Locations[4]>1000) THEN PULSE(number_of_cleaner_fish_introduced[4]; Time_of_introduction; refilling_time) ELSE 0	fish/day
OUTFLOWS: Cleaner_fish_mortality[1] = Cleaner_fish[1]*CF_MR Cleaner_fish_mortality[2] = Cleaner_fish[2]*CF_MR Cleaner_fish_mortality[3] = Cleaner_fish[3]*CF_MR Cleaner_fish_mortality[4] = Cleaner_fish[4]*CF_MR	fish/day
Cleaner_Salmon_Ratio[1] = MIN(MAX(0;	dmnl

Cleaner_fish/(Locations[1]+0,0001)); 1) Cleaner_Salmon_Ratio[2] = MIN(MAX(0; Cleaner_fish/(Locations[2]+0,0001)); 1) Cleaner_Salmon_Ratio[3] = MIN(MAX(0; Cleaner_fish/(Locations[3]+0,0001)); 1) Cleaner_Salmon_Ratio[4] = MIN(MAX(0; Cleaner_fish/(Locations[4]+0,0001)); 1)	
mortality_from_cleaner_fish[1] = 1-EXP(-0,0823*Cleaner_Salmon_Ratio[1]) mortality_from_cleaner_fish[2] = 1-EXP(-0,0823*Cleaner_Salmon_Ratio[2]) mortality_from_cleaner_fish[3] = 1-EXP(-0,0823*Cleaner_Salmon_Ratio[3]) mortality_from_cleaner_fish[4] = 1-EXP(-0,0823*Cleaner_Salmon_Ratio[4])	dmnl
number_of_cleaner_fish_introduced[1] = 10000 number_of_cleaner_fish_introduced[2] = 10000 number_of_cleaner_fish_introduced[3] = 10000 number_of_cleaner_fish_introduced[4] = 10000	fish
refilling_time = 50	days
Time_of_introduction[1] = 250 Time_of_introduction[2] = 250 Time_of_introduction[3] = 250 Time_of_introduction[4] = 250	days

Infection Pressure Sector

Equations and Comments	**Unit**
alfa_test = 1/360*20	dmnl
alfa_val_in_dir_of = 0,0556 *direction of pressure, as a sector of a 360 degree dispersal that is 1. 1/360 is 0,002 so 20degrees is 0,056*	dmnl
Attachment_rate[1] = (IP_i[1]*Copepodid[1]+IP_j[1]*Copepodid[2]+IP_k[1]*Copepodid[3]+IP_l[1]*Copepodid[4]) Attachment_rate[2] = (IP_i[2]*Copepodid[1]+IP_j[2]*Copepodid[2]+IP_k[2]*Copepodid[3]+IP_l[2]*Copepodid[4]) Attachment_rate[3] = (IP_i[3]*Copepodid[1]+IP_j[3]*Copepodid[2]+IP_k[3]*Copepodid[3]+IP_l[3]*Copepodid[4]) Attachment_rate[4] = (IP_i[4]*Copepodid[1]+IP_j[4]*Copepodid[2]+IP_k[4]*Copepodid[3]+IP_l[4]*Copepodid[4]) *The rate at which infectious stage lice are able to develop, find a host and attach to a fish.*	lice/days
host_availability_P[1] = IF(Host_population[1]>1000) THEN 1 ELSE 0 host_availability_P[2] = IF(Host_population[2]>1000) THEN 1 ELSE 0 host_availability_P[3] = IF(Host_population[3]>1000) THEN 1 ELSE 0 host_availability_P[4] = IF(Host_population[4]>1000) THEN 1 ELSE 0	dmnl
Host_population[1] = Locations[1]+Wild_hosts/4 Host_population[2] = Locations[2]+Wild_hosts/4 Host_population[3] = Locations[3]+Wild_hosts/4 Host_population[4] = Locations[4]+Wild_hosts/4	fish

IP_i[1] = "Si_x_P(B)"[1]*alfa_val_in_dir_of*host_availability_P[1] IP_i[2] = "Si_x_P(B)"[2]*alfa_val_in_dir_of*host_availability_P[1] IP_i[3] = "Si_x_P(B)"[3]*alfa_val_in_dir_of*host_availability_P[1] IP_i[4] = "Si_x_P(B)"[4]*alfa_val_in_dir_of*host_availability_P[1] *The force of infection between locations. "This feedback dynamic can be confirmed by calculating the* *loop polarity in the SIR model. As the number of infected cases increase, so too does lambda. An* *increase in lambda leads to an increased in the infection rate (IR), which in turn leads to higher* *numbers of infected. This is a reinforcing process, and the positive feedback loop can quickly dominate* *the model behavior and so drive the exponential growth processes associated with the outbreak of a* *contagious disease."* *Duggan (2016)* *Kristoffersen et al 2014 estimates the internal infection pressure as 0 most of the first 16 weeks, while* *EIP is significant correlated with louse counts.*	Dmnl/days
IP_j[1] = "Sj_x_P(B)"[1]*alfa_val_in_dir_of*host_availability_P[2] IP_j[2] = "Sj_x_P(B)"[2]*alfa_val_in_dir_of*host_availability_P[2] IP_j[3] = "Sj_x_P(B)"[3]*alfa_val_in_dir_of*host_availability_P[2] IP_j[4] = "Sj_x_P(B)"[4]*alfa_val_in_dir_of*host_availability_P[2]	Dmnl/days
IP_k[1] = "Sk_x_P(B)"[1]*alfa_val_in_dir_of*host_availability_P[3] IP_k[2] = "Sk_x_P(B)"[2]*alfa_val_in_dir_of*host_availability_P[3] IP_k[3] = "Sk_x_P(B)"[3]*alfa_val_in_dir_of*host_availability_P[3] IP_k[4] = "Sk_x_P(B)"[4]*alfa_val_in_dir_of*host_availability_P[3]	Dmnl/days
IP_l[1] = "Sl_x_P(B)"[1]*alfa_val_in_dir_of*host_availability_P[4] IP_l[2] = "Sl_x_P(B)"[2]*alfa_val_in_dir_of*host_availability_P[4] IP_l[3] = "Sl_x_P(B)"[3]*alfa_val_in_dir_of*host_availability_P[4] IP_l[4] = "Sl_x_P(B)"[4]*alfa_val_in_dir_of*host_availability_P[4]	Dmnl/days
"Si_x_P(B)"[1] = Survival_from_i[1] "Si_x_P(B)"[2] = Survival_from_i[2] "Si_x_P(B)"[3] = Survival_from_i[3] "Si_x_P(B)"[4] = Survival_from_i[4] *Kristoffersen et al 2017: To Model Spatial Infestation Pressure, the farm specific estimates of* *infestation pressure are interpolated in coastal waters from the farm origin, using an empirical kernel* *density function (Aldrin et al 2013). Infestation pressure at any point is thus expressed as the distance-* *adjusted sum of cotnributions from all farms within 100 km seaway distance.* *RR i,j=* *e^(-1.444-0,351(D i,j ^(0,57)-1/0,57)/* *e^(-1,444-0,351(0-1)/0,57)* *where D i,j is the seaway distance from farm i to location j along the coast. Infestation pressure from* *farms more distant than 100km was set to 0.*	Dmnl/days
"Sj_x_P(B)"[1] = Survival_from_j[1] "Sj_x_P(B)"[2] = Survival_from_j[2] "Sj_x_P(B)"[3] = Survival_from_j[3] "Sj_x_P(B)"[4] = Survival_from_j[4]	Dmnl/days
"Sk_x_P(B)"[1] = Survival_from_k[1] "Sk_x_P(B)"[2] = Survival_from_k[2]	Dmnl/days

"Sk_x_P(B)"[3] = Survival_from_k[3] "Sk_x_P(B)"[4] = Survival_from_k[4]	
"Sl_x_P(B)"[1] = Survival_from_l[1] "Sl_x_P(B)"[2] = Survival_from_l[2] "Sl_x_P(B)"[3] = Survival_from_l[3] "Sl_x_P(B)"[4] = Survival_from_l[4]	Dmnl/days
Survival_from_i[1] = 0,3104 Survival_from_i[2] = 4,148E-07 Survival_from_i[3] = 2,584E-13 Survival_from_i[4] = 3,260E-14 *This is known as the basic reproduction number R0, which is the average number of secondary infectious persons resulting from one infectious person being introduced to a totally susceptible population (Anderson and May 1992). Effective contact rate *total population gives the real transmission parameter*	Dmnl/days
Survival_from_k[1] = 1,928E-13 Survival_from_k[2] = 1,377E-14 Survival_from_k[3] = 0,3104 Survival_from_k[4] = 4,148E-07	Dmnl/days

Lice Sector

Equations and Comments	**Unit**
Adult[1](t) = Adult[1](t - dt) + (Maturing[1] - Mature_Mortality[1] - Treatment_Mortality_AL[1]) * dt INIT Adult[1] = 100 Adult[2](t) = Adult[2](t - dt) + (Maturing[2] - Mature_Mortality[2] - Treatment_Mortality_AL[2]) * dt INIT Adult[2] = 100 Adult[3](t) = Adult[3](t - dt) + (Maturing[3] - Mature_Mortality[3] - Treatment_Mortality_AL[3]) * dt INIT Adult[3] = 100 Adult[4](t) = Adult[4](t - dt) + (Maturing[4] - Mature_Mortality[4] - Treatment_Mortality_AL[4]) * dt INIT Adult[4] = 100	Lice
INFLOWS: Maturing[Location] = MAX(0; Chalimus_and_Preadult/Maturing_time_PAAM)	Lice/days
OUTFLOWS: Mature_Mortality[Location] = Adult/life_span Treatment_Mortality_AL[Location] = MAX(0; (Adult*Treatment_MR)-Mature_Mortality-(Lice_removed_with_slaughtered_fish*Ad_fraction))	Lice/days
"Attached_Lice_stages_per_fish,_all_locations" = (lice_pr_fish[1]+lice_pr_fish[2]+lice_pr_fish[3]+lice_pr_fish[4])/4	Lice/fish
Avg_development_time = 17	days
Preadult[Location](t) = Preadult[Location](t - dt) + (Developing[Location] - Maturing[Location] - Pa_Mortality[Location] - Treatment_MR_on_PA[Location]) * dt INIT Preadult[Location] = 150	lice
INFLOWS: Developing[Location] = Chalimus/Dev_time_to_PA	Lice/days

OUTFLOWS: Maturing[Location] = MAX(0; Preadult/Maturing_time_to_AL) Pa_Mortality[Location] = Preadult/Life_duration Treatment_MR_on_PA[Location] = MAX(0; (Preadult*Treatment_MR)-Pa_Mortality-(Lice_removed_with_slaughtered_fish*(1-Fraction_adult_Lice)))	
Chalimus[Location](t) = Chalimus[Location](t - dt) + (Attaching[Location] - Developing[Location] - CH_Mortality[Location] - Treatment_Mortality_Chalimus[Location]) * dt INIT Chalimus[Location] = 100	Lice
INFLOWS: Attaching[1] = MAX(0; Attachment_rate[1]) Attaching[2] = Attachment_rate[2] Attaching[3] = Attachment_rate[3] Attaching[4] = Attachment_rate[4] UNITS: lice/days OUTFLOWS: Developing[Location] = Chalimus/Dev_time_to_PA CH_Mortality[Location] = Chalimus/CH_life_dur	Lice/days
Treatment_Mortality_Chalimus[Location] = MAX(0; (Chalimus* treatment_effect_on_mortality/treatment_effect_delay)-CH_Mortality)	Lice/days
Copepodid[1](t) = Copepodid[1](t - dt) + (Infectious_development[1] - Attaching[1] - Unattached_Mortality[1]) * dt INIT Copepodid[1] = 100 Copepodid[2](t) = Copepodid[2](t - dt) + (Infectious_development[2] - Attaching[2] - Unattached_Mortality[2]) * dt INIT Copepodid[2] = 100 Copepodid[3](t) = Copepodid[3](t - dt) + (Infectious_development[3] - Attaching[3] - Unattached_Mortality[3]) * dt INIT Copepodid[3] = 100 Copepodid[4](t) = Copepodid[4](t - dt) + (Infectious_development[4] - Attaching[4] - Unattached_Mortality[4]) * dt INIT Copepodid[4] = 100	lice
INFLOWS: Infectious_development[Location] = "Nauplii_(larvae)"/Development_time	Lice/days
OUTFLOWS: Attaching[1] = MAX(0; Attachment_rate[1]) Attaching[2] = Attachment_rate[2] Attaching[3] = Attachment_rate[3] Attaching[4] = Attachment_rate[4] Unattached_Mortality[Location] = Copepodid/Copepodid_stage_time	Lice/days
Copepodid_stage_time = Normal_stage_time/(1/Effect_of_temperature_on_stage_time) *During the period of development through to chalimus stages we assumed a daily mortality of 0,05per individual (Stien et al 2005), where delta Tch is the number of days required to accumulate 155degree-days with the given temperatures.*	days
Development_time = norm_dev_time/(1/Effect_of_temperature_on_stage_time)	days
Effect_of_season_on_wild_hosts = GRAPH(season) (0, 0,200), (96,0526315789, 0,800), (192,105263158, 0,700), (288,157894737,	dmnl

0,300), (384,210526316, 0,400), (480,263157895, 0,200), (576,315789474, 0,800), (672,368421053, 0,700), (768,421052632, 0,300), (864,473684211, 0,400), (960,526315789, 0,200), (1056,57894737, 0,800), (1152,63157895, 0,700), (1248,68421053, 0,300), (1344,73684211, 0,400), (1440,78947368, 0,200), (1536,84210526, 0,800), (1632,89473684, 0,700), (1728,94736842, 0,300), (1825, 0,400) *wild stocks migrate into the fjord and up rivers for nesting late winter and early spring. migration out of the fjord occurs during summer and autumn. There are no lice in fresh water (rivers) and in the sea their reproduction rate is low due to the spread of hosts over much larger areas than when in the fjord.*	
Effect_of_temperature_on_egg_development_time = GRAPH(Historical_temperature) (0,00, 0,00), (1,00, 0,00), (2,00, 0,00), (3,00, 0,00), (4,00, 26,28), (5,00, 20,87), (6,00, 16,97), (7,00, 14,08), (8,00, 11,86), (9,00, 10,13), (10,00, 8,75), (11,00, 7,64), (12,00, 6,72), (13,00, 5,96), (14,00, 5,33), (15,00, 4,79), (16,00, 4,32), (17,00, 3,93)	dmnl
effect_of_temperature_on_lice_lifespan = Historical_temperature/mean_temperature	dmnl
Effect_of_temperature_on_stage_time = mean_temp/Historical_temperature	dmnl
Effect_of_temperature_on_stage_time_1 = Historical_temperature/mean_temp_1	dmnl
egg_stage_development_time = Effect_of_temperature_on_egg_development_time	days
Egg_survival_time = 6	days
Eggs[Location](t) = Eggs[Location](t - dt) + (LS_Eggs_in[Location] - Hatching[Location] - Eggs_mortality[Location]) * dt INIT Eggs[Location] = 100	lice
INFLOWS: LS_Eggs_in[Location] = eggs_produced	Lice/days
OUTFLOWS: Hatching[Location] = Eggs/Hatching_time Eggs_mortality[Location] = Eggs/Egg_survival_time	Lice/days
Eggs_pr_louse_per_day = GRAPH(Historical_temperature) (0,00, 0,00), (1,00, 0,00), (2,00, 0,00), (3,00, 0,00), (4,00, 26,28), (5,00, 20,87), (6,00, 16,97),(7,00, 14,08), (8,00, 11,86), (9,00, 10,13), (10,00, 8,75), (11,00, 7,64), (12,00, 6,72), (13,00,5,96), (14,00, 5,33), (15,00, 4,79), (16,00, 4,32), (17,00, 3,93)	Dmnl/days
eggs_produced[Location] = MAX(0; Female_Lice*Eggs_pr_louse_per_day)	Lice/days
Event_switch = 0	dmnl
Female_Lice[Location] = Adult*Fraction_Female	Lice
Fraction_Female = 0,50	dmnl
Hatching_time = egg_stage_development_time	days
Historical_temperature = GRAPH(TIME) (0, 6,20), (31, 5,40), (59, 5,30), (90, 6,50), (120, 9,70), (151, 12,60), (181, 15,20), (212,15,50), (243, 13,50), (273, 10,90), (304, 8,70), (334, 8,00), (365, 6,20), (396, 5,40), (424,5,30), (455, 6,50), (485, 9,70), (516, 12,60), (546, 15,20), (577, 15,50), (608, 13,50), (638,10,90), (669, 8,70), (699, 8,00), (730, 6,20), (761, 5,40), (789, 5,30), (820, 6,50), (850, 9,70), (881, 12,60), (911, 15,20), (942, 15,50), (973, 13,50), (1003, 10,90), (1034, 8,70), (1064,8,00), (1095, 6,20), (1126, 5,40), (1154, 5,30), (1185, 6,50), (1215, 9,70),	Degrees C

(1246, 12,60),(1276, 15,20), (1307, 15,50), (1338, 13,50), (1368, 10,90), (1399, 8,70), (1429, 8,00), (1460,6,20), (1491, 5,40), (1519, 5,30), (1550, 6,50), (1580, 9,70), (1611, 12,60), (1641, 15,20),(1672, 15,50), (1703, 13,50), (1733, 10,90), (1764, 8,70), (1794, 8,00), (1825, 6,20)	
lice_pr_fish[1] = IF Locations[1]>5000 THEN "Mob_/_Mot_lice_in_locations"[1]/(Locations[1]+Wild_hosts) ELSE 0 lice_pr_fish[2] = IF Locations[2]>5000 THEN "Mob_/_Mot_lice_in_locations"[2]/(Locations[2]+Wild_hosts) ELSE 0 lice_pr_fish[3] = IF Locations[3]>5000 THEN "Mob_/_Mot_lice_in_locations"[3]/(Locations[3]+Wild_hosts) ELSE 0 lice_pr_fish[4] = IF Locations[4]>5000 THEN "Mob_/_Mot_lice_in_locations"[4]/(Locations[4]+Wild_hosts) ELSE 0	Lice/fish
Lice_removed_with_slaughtered_fish[Location] = MAX(0; MIN(("Mob_/_Mot_lice_in_locations"/Slaughter_time); lice_pr_fish*Weight_Slaughter))	Lice/days
Life_duration = 20	days
life_span[Location] = normal_life_span*(1/effect_of_temperature_on_lice_lifespan)	days
Maturing_time_PAAM = Avg_development_time*Effect_of_temperature_on_stage_time_1	days
mean_temp = 10	Degrees C
mean_wild_stock = 6000	fish
"Mob_/_Mot_lice_in_locations"[1] = MAX(0; (Chalimus_and_Preadult[1]+Adult[1])) "Mob_/_Mot_lice_in_locations"[2] = MAX(0; (Chalimus_and_Preadult[2]+Adult[2])) "Mob_/_Mot_lice_in_locations"[3] = MAX(0; (Chalimus_and_Preadult[3]+Adult[3])) "Mob_/_Mot_lice_in_locations"[4] = MAX(0; (Chalimus_and_Preadult[4]+Adult[4]))	lice
"Nauplii_(larvae)"[1](t) = "Nauplii_(larvae)"[1](t - dt) + (Hatching[1] - Nauplius_Mortality[1] - Infectious_development[1]) * dt INIT "Nauplii_(larvae)"[1] = 100 "Nauplii_(larvae)"[2](t) = "Nauplii_(larvae)"[2](t - dt) + (Hatching[2] - Nauplius_Mortality[2] - Infectious_development[2]) * dt INIT "Nauplii_(larvae)"[2] = 100 "Nauplii_(larvae)"[3](t) = "Nauplii_(larvae)"[3](t - dt) + (Hatching[3] - Nauplius_Mortality[3] - Infectious_development[3]) * dt INIT "Nauplii_(larvae)"[3] = 100 "Nauplii_(larvae)"[4](t) = "Nauplii_(larvae)"[4](t - dt) + (Hatching[4] - Nauplius_Mortality[4] - Infectious_development[4]) * dt INIT "Nauplii_(larvae)"[4] = 100	lice
INFLOWS: Hatching[Location] = Eggs/Hatching_time	Lice/days
OUTFLOWS: Nauplius_Mortality[Location] = "Nauplii_(larvae)"*Nauplii_Mortality_R Infectious_development[Location] = "Nauplii_(larvae)"/Development_time	Lice/days
Nauplii_Mortality_R = 0,17	1/days
norm_dev_time = 4,5	days
normal_life_span = 15,5	days
Normal_stage_time = 15,5	days
Percentage_of_normal = 0,8	dmnl
season = TIME	days

Summer_event = IF Historical_temperature > 9,6 THEN Percentage_of_normal ELSE 1	dmnl
Temperature = IF Event_switch = 1 THEN Historical_temperature*Summer_event ELSE Historical_temperature+Temperature_change *Same as Historical Temperature. Variable exists incase we want to test the effect of temperatures other than the historical temperature*	Degrees C
Temperature_change = 0	Degrees C
Times_when_fish_reach_their_desired_fish_weight[1] = IF Fish_Weight[1] >= Desired_Fish_Weight THEN 1 ELSE 0 Times_when_fish_reach_their_desired_fish_weight[2] = IF Fish_Weight[2] >= Desired_Fish_Weight THEN 1 ELSE 0 Times_when_fish_reach_their_desired_fish_weight[3] = IF Fish_Weight[3] >= Desired_Fish_Weight THEN 1 ELSE 0 Times_when_fish_reach_their_desired_fish_weight[4] = IF Fish_Weight[4] >= Desired_Fish_Weight THEN 1 ELSE 0	Grams
Treatment_MR[Location] = life_span_reduction_during_treatment	1/days
Wild_hosts = Effect_of_season_on_wild_hosts*mean_wild_stock	Fish

Treatments Sector

Equations and Comments	**Unit**
Ad_fraction = Adult[1]/(Chalimus_and_Preadult[1]+Adult[1])	dmnl
allowed_lice_pr_fish = 0,5	Lice/fish
Closest_Neighbour[1] = CN_Switch*((treatment_initiation[1]+treatment_initiation[2])) Closest_Neighbour[2] = CN_Switch*((treatment_initiation[2]+treatment_initiation[1])) Closest_Neighbour[3] = CN_Switch*((treatment_initiation[3]+treatment_initiation[4])) Closest_Neighbour[4] = CN_Switch*((treatment_initiation[4]+treatment_initiation[3])) *Cooperative treatment of the original location with high lice abundance, and its closest neighbor. Distance being the main determinant of external infection pressure, this takes some of the external pressure off, and could be an alternative between treating all (full coordination) and treating only one.*	dmnl
CN_Switch = 0	dmnl
effect_gap[Location] = Treatment_effectiveness*treatment_effect_on_effectiveness	Dmnl/days
Feeding_pause_time = 5	days
fraction_female_lice = 0,5	dmnl
Last_treatment_time[Cohorts](t) = Last_treatment_time[Cohorts](t - dt) + (C_Treatment[Cohorts]) * dt INIT Last_treatment_time[Cohorts] = 0	days
INFLOWS: C_Treatment[Cohorts] = IF Time_when_treatment_occurs >0 THEN (Time_when_treatment_occurs-Last_treatment_time)/DT ELSE 0	dmnl
life_span_reduction_during_treatment[Location] = PULSE ((treatment_effect_on_mortality); treatment_effect_delay	1/days
Single_Loc[1] = SL_Switch*treatment_initiation[1]	dmnl

Single_Loc[2] = SL_Switch*treatment_initiation[2] Single_Loc[3] = SL_Switch*treatment_initiation[3] Single_Loc[4] = SL_Switch*treatment_initiation[4] *The single location policy only treats the location that have high lice counts. Other locations go untreated until they reach the threshold themselves. This is equivalent to no coordination*	
SL_Switch = 1	dmnl
Time_when_feeding_starts_again[1] = IF Last_treatment_time[1] > 0 THEN Last_treatment_time[1] + Feeding_pause_time ELSE 0 Time_when_feeding_starts_again[2] = Last_treatment_time[2] + Feeding_pause_time Time_when_feeding_starts_again[3] = Last_treatment_time[3] + Feeding_pause_time Time_when_feeding_starts_again[4] = Last_treatment_time[4] + Feeding_pause_time	days
Time_when_treatment_occurs[1] = IF treatment_increase[1] > 0 THEN TIME ELSE 0 Time_when_treatment_occurs[2] = IF treatment_increase[2] > 0 THEN TIME ELSE 0 Time_when_treatment_occurs[3] = IF treatment_increase[3] > 0 THEN TIME ELSE 0 Time_when_treatment_occurs[4] = IF treatment_increase[4] > 0 THEN TIME ELSE 0	days
Time_with_no_feeding_due_to_treatment[1] = IF TIME >= Last_treatment_time[1] AND TIME <= Time_when_feeding_starts_again[1] THEN 1 ELSE 0 Time_with_no_feeding_due_to_treatment[2] = IF TIME >= Last_treatment_time[2] AND TIME <= Time_when_feeding_starts_again[2] THEN 1 ELSE 0 Time_with_no_feeding_due_to_treatment[3] = IF TIME >= Last_treatment_time[3] AND TIME <= Time_when_feeding_starts_again[3] THEN 1 ELSE 0 Time_with_no_feeding_due_to_treatment[4] = IF TIME >= Last_treatment_time[4] AND TIME <= Time_when_feeding_starts_again[4] THEN 1 ELSE 0	days
treatment_effect_delay = 2	days
Tot_Treatments_used = Treatments_used[1]+Treatments_used[2]+Treatments_used[3]+Treatments_used[4]	dmnl
treatment_effect_on_effectiveness[Location] = Treatment_regularity*0,00000001 *Diminishing effect from high chemical use. More data is needed for the correct weight of this* *phenomenon.*	Dmnl/days
treatment_effect_on_mortality[1] = Single_Loc[1]+All_delayed[1]+Closest_Neighbour[1]*Treatment_effectiveness +mortality_from_cleaner_fish[1] treatment_effect_on_mortality[2] = Single_Loc[2]+All_delayed[2]+Closest_Neighbour[2]*Treatment_effectiveness +mortality_from_cleaner_fish[2] treatment_effect_on_mortality[3] = Single_Loc[3]+All_delayed[3]+Closest_Neighbour[3]*Treatment_effectivenes	dmnl

s +mortality_from_cleaner_fish[3] treatment_effect_on_mortality[4] = Single_Loc[4]+All_delayed[4]+Closest_Neighbour[4]*Treatment_effectivenes s +mortality_from_cleaner_fish[4]	
Treatment_effectiveness(t) = Treatment_effectiveness(t - dt) + (Increase_in_eff - Decrease_in_effectiveness) * dt INIT Treatment_effectiveness = 1	dmnl
INFLOWS Increase_in_eff = 0 OUTFLOWS Decrease_in_effectiveness = effect_gap[1]+effect_gap[2]+effect_gap[3]+effect_gap[4]	Dmnl/days
treatment_indicator[Location] = MAX(0; lice_pr_fish*fraction_female_lice/allowed_lice_pr_fish)	dmnl
treatment_initiation[1] = treatment_switch* (IF(treatment_indicator[1]>0,9) THEN PULSE (1; 1,) ELSE 0) treatment_initiation[2] = treatment_switch* (IF(treatment_indicator[2]>0,9) THEN PULSE (1; 1,) ELSE 0) treatment_initiation[3] = treatment_switch* (IF(treatment_indicator[3]>0,9) THEN PULSE (1; 1,) ELSE 0) treatment_initiation[4] = treatment_switch* (IF(treatment_indicator[4]>0,9) THEN PULSE (1; 1,) ELSE 0)	dmnl
treatment_intervals = DT	Days
Treatment_regularity[1] = Treatments_used[1]/treatment_intervals Treatment_regularity[2] = Treatments_used[2]/treatment_intervals Treatment_regularity[3] = Treatments_used[3]/treatment_intervals Treatment_regularity[4] = Treatments_used[4]/treatment_intervals	Dmnl/days
treatment_switch = 1	Dmnl
Treatments_used[1](t) = Treatments_used[1](t - dt) + (treatment_increase[1]) * dt INIT Treatments_used[1] = 0 Treatments_used[2](t) = Treatments_used[2](t - dt) + (treatment_increase[2]) * dt INIT Treatments_used[2] = 0 Treatments_used[3](t) = Treatments_used[3](t - dt) + (treatment_increase[3]) * dt INIT Treatments_used[3] = 0 Treatments_used[4](t) = Treatments_used[4](t - dt) + (treatment_increase[4]) * dt INIT Treatments_used[4] = 0	Dmnl
INFLOWS: treatment_increase[1] = (Single_Loc[1]+All_delayed[1]+Closest_Neighbour[1])/DT treatment_increase[2] = (Single_Loc[2]+All_delayed[2]+Closest_Neighbour[2])/DT treatment_increase[3] =	Dmnl/days

(Single_Loc[3]+All_delayed[3]+Closest_Neighbour[3])/DT treatment_increase[4] = (Single_Loc[4]+All_delayed[4]+Closest_Neighbour[4])/DT	

Appendix C – Equations –Economic Sector

Model Formulations for Economics Sector

Formulations and comments	Units
Revenue[Location](t) = Revenue[Location](t - dt) + (Revenue_Flow[Location] - Revenue_Reset[Location]) * dt *This stock accumulates the revenues in the system and distributes it throughout the year. There are four locations arrayed together to show the revenue separately for each location.*	Norwegian kronor (NOK)
Revenue_Flow[Location] = Fish_Market_Price*Net_Slaughtered_Weight[Location] *Revenue is a function of the Fish Market Price and Net Slaughtered weight. There are four flows for four locations to flow the revenues separately.*	Norwegian kronor per day (NOK/Day)
Income_Reset[Location] = (Revenue[Location]/Days_to_Resrt_Revenue) *This Outflow helps to distribute the stock evenly throughout the year since revenue is generating once or twice in a year. It works as a material delay.*	Norwegian kronor per day (NOK/Day)
Net_Slaughtered_Weight[Location] = Total_Slaughtered_Weight[Location]*"Net_Biomass_Weight/Kg" *Net Slaughtered Weight is calculated based on the net edible meat of the fish.*	Kilogram per Day (Kg/Day)
Total_Slaughtered_Weight[Location] = Total_Slaughter[Location]*Fish_weight_converted_to_KG[Location] *Total Slaughtered weight is converted to Kilogram.*	Kilogram per Day (Kg/Day)
Total_Slaughter[Location] = Weight_Slaughter[Location]+Slaughter_based_on_Biomass[Location] *Total slaughter is the sum of weight slaughter per location and slaughter based on Biomass.*	Fish per Day (Fish/Day)
Fish_Market_Price[Location] = IF Fish_weight_converted_to_KGLocation>0.5 AND Fish_weight_converted_to_KGLocation<1 THEN "1_Kg_Fish_Price" ELSE IF Fish_weight_converted_to_KGLocation>=1 AND Fish_weight_converted_to_KG[Location]<=2 THEN "1-2KG_Fish_Price" ELSE IF Fish_weight_converted_to_KG[Location]>2 AND	Norwegian kronor per Kilogram (NOK/Kg)

Fish_weight_converted_to_KG[Location]<= 3 THEN "2-3_KG_Fish_Price" ELSE IF Fish_weight_converted_to_KG[Location]>3 AND Fish_weight_converted_to_KG[Location]<=4 THEN "3-4_KG_Fish_Price" ELSE IF Fish_weight_converted_to_KG Location >4 AND Fish_weight_converted_to_KGLocation<=5 THEN "4-5_KG_Fish_Price" ELSE 0 *Fish price is a function of the fish weight and the historical data of weight class price. There are 5 different weight class data has been used for this model based on the NASDAQ Salmon Index –Price Per Weight Class.*	
Fish_weight_converted_to_KG[Location] = Fish_Weight[Location]/grams_to_kg_Conversion *Fish weight is converted from grams to KG.*	Kilogram per Fish (Kilograms/Fish)
Total_Slaughtered_weight_for_all_location = Total_Slaughtered_Weight[Location]+Total_Slaughtered_Weight[Location]+Total_Slaughtered_Weight[Location]+Total_Slaughtered_Weight[Location] *Total slaughtered weight form different locations are accumulated here.*	Kilogram per Day (Kg/Day)
Expenses[Location](t) = Expenses[Location](t - dt) + (Expense_Flow[Location] - Expense_Reset[Location]) * dt *This stock accumulates the expenses in the system and distributes it throughout the year. There are four locations arrayed together to show the expenses separately for each location.*	Norwegian kronor (NOK)
Expense_Flow[Location] = Total_Operating_Expenses[Location] *Expense flow flows total operating expenses to the stock*	Norwegian kronor per day (NOK/Day)
Expense_Reset[Location] = (Expenses[Location]/Days_to_Reset_Expenses) *This Outflow helps to distribute the stock evenly throughout the year since expense is incurred every day throughout the production. It works as a material delay.*	Norwegian kronor per day (NOK/Day)
Total_Operating_Expenses[Location] = Total_Labor_cost_per_Location[Location]+ "Total_Feeding_Cost/day/Location"[Location]+ Total_Slaughtering_Cost[Location] + "Smolt_Cost/Location"[Location] +Treatment_cost[Location] *Total operating expenses are sum of all direct costs involved in the operation. This is an arrayed variable that counts expenses separately for different locations.*	Norwegian kronor per day (NOK/Day)
Total_ Operating _Expense_for_all_Location = Total_Operating_Expenses[Location]+Total_Operating_Expenses[Location]+Total_Operating_Expenses[Location]+Total_Operating_Expenses[Location]	Norwegian kronor per day (NOK/Day)

Total operating expenses from different locations are accumulating here.	
Total_Labor_cost_per_Location[Location] = (Annual_Cost_per_workforce_inc_TAX_1/Year_to_Day_Conversion)*Number_of_workforce_per_Location *Here total labor force cost per location is calculated based on the number of workforce per location and cost per workforce. Then the value is converted from per year to per day.*	Norwegian kronor per day (NOK/Day)
Total_Labor_cost_for_all_Locations = Total_Labor_cost_per_Location[Location]+Total_Labor_cost_per_Location[Location]+Total_Labor_cost_per_Location[Location]+Total_Labor_cost_per_Location[Location] *Total workforce expenses for the operation are accumulated here.*	Norwegian kronor per day (NOK/Day)
Number_of_workforce_per_Location = Total_Workforce/Number_of_Location *Average number of workforce per location is calculated based on the total employees divided by the number of production sites.*	Employees (Employees)
Total_Workforce = Operational_workforce+Operational_Fixed_Workforce *This accumulates the sum of operational fixed workforce and operational temporary workforce.*	Employees (Employees)
Operational_workforce = (Total_Biomass*ton_to_kg_conversion)/Temporary_Workforce_based_on_the_production *Operational workforces are calculated based on the total produced biomass. It is anticipated that for every 300000 KG of biomass production an extra operational employee is required.*	Employees (Employees)
"Total_Feeding_Cost/day/Location"[Location] = "Total_Food_Consumption/day/Location"[Location]*Per_KG_Feed_Cost *Total Feeding cost is a function of total food required per day times the feed cost per KG. Here feeding costs are calculating for individual locations.*	Norwegian kronor per day (NOK/Day)
Total_Feed_Cost_for_all_Location = "Total_Feeding_Cost/day/Location"[Location] + "Total_Feeding_Cost/day/Location"[Location] + "Total_Feeding_Cost/day/Location"[Location] + "Total_Feeding_Cost/day/Location"[Location] *This accumulates the sum of feeding costs for all locations for entire period.*	Norwegian kronor per day (NOK/Day)
"Total_Food_Consumption/day/Location"[Location] = (Amount_of_fish_food_per_day[Location]/grams_to_kg_Conversion)*Location	Kilogram per Day (Kg/Day)

s[Location] *This is the total food that need per location for everyday's production that is calculated based on the number of fish per location and food required per fish per day.*	
"Smolt_Cost/Location"[Location] = To_Sea[1,1]*"Cost/Smolt" *Smolt cost per location is calculated based on the number of smolts are released per location times the cost per smolt.*	Norwegian kronor per day (NOK/Day)
Total_Smolt_Cost_for_all_location = "Smolt_Cost/Location"[Location]+"Smolt_Cost/Location"[Location]+"Smolt_Cost/Location"[Location]+"Smolt_Cost/Location"[Location] *This is the sum of total smolt costs for the operation for entire period.*	Norwegian kronor per day (NOK/Day)
"Cost/Smolt" = GRAPH(Desired_Smolt_weight[Location]) (100.0, 15.000), (150.0, 15.500), (200.0, 16.000), (250.0, 16.500), (300.0, 17.000), (350.0, 17.500), (400.0, 18.000), (450.0, 19.000), (500.0, 20.000) *Smolt cost is a function of desired smolt weight. Higher weight cost high than lower weight.*	Norwegian kronor per Fish (NOK/Fish)
Treatment_cost[Location] = Cost_of_treatment_per_fish*Fish_Treated[Location] *Treatment cost includes any sorts of expenses regarding fish treatment in the production period. This is calculated based on the number of fish treated times cost of treating per fish.*	Norwegian kronor per day (NOK/Day)
Total_Treatment_cost_for_all_Locations = Treatment_cost[Location]+Treatment_cost[Location]+Treatment_cost[Location]+Treatment_cost[Location] *This is the sum of total treatment costs for the operation for entire period.*	Norwegian kronor per day (NOK/Day)
Fish_Treated[Location] = treatment_increase[Location]*Locations[Location] *Number of treated fish is calculated based on the number of fish times treatment process*	Fish per day (Fish/Day)
Total_Slaughtering_Cost[Location] = Total_Slaughtered_Weight[Location]*"Slaughtering_kost/Kg" *Total slaughtering cost is calculated based on the total slaughtered fish weight times cost of slaughtering per kg fish.*	Norwegian kronor per day (NOK/Day)
Total_Slaughtering_Cost_for_all_Location = Total_Slaughtering_Cost[Location]+Total_Slaughtering_Cost[Location]+Total_Slaughtering_Cost[Location]+Total_Slaughtering_Cost[Location] *This accumulates the total slaughtering cost for all the locations for the entire production period.*	Norwegian kronor per day (NOK/Day)

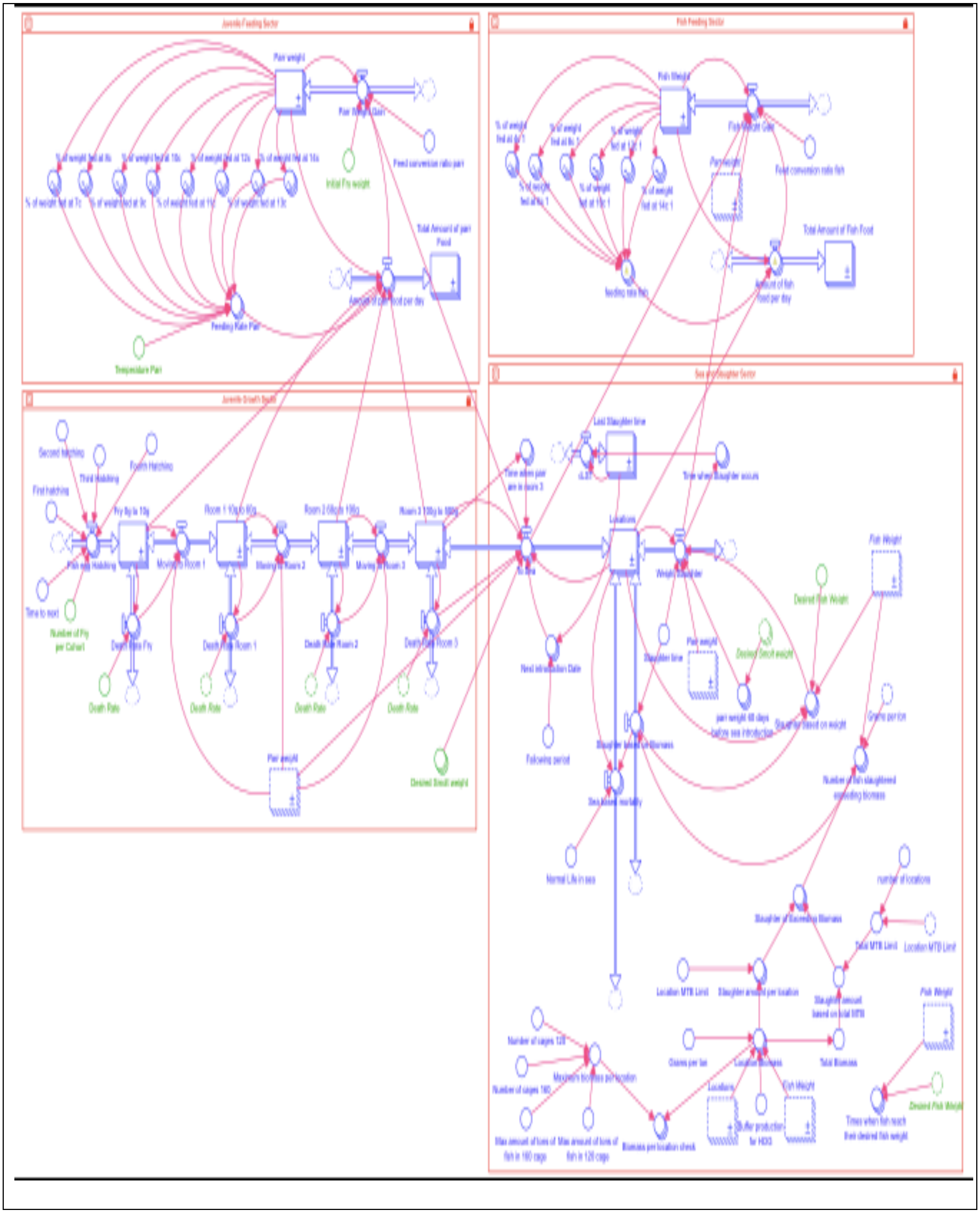
Total_Accumulated_Expense_for_All_Location = Expenses[Location]+Expenses[Location]+Expenses[Location]+Expenses[Location] *This is the sum of all expenses are incurred for all the locations for the entire operation period.*	Norwegian kronor (NOK)
Total_Accumulated_Revenue_for_All_Location = Revenue[Location]+Revenue[Location]+Revenue[Location]+Revenue[Location] *This is the accumulation of all the revenues are earned for all the locations for the entire operation period.*	Norwegian kronor (NOK)
Total_Gross_Profit_for_All_Locations = Total_Accumulated_Revenue_for_All_Location-Total_Accumulated_Expense_for_All_Location *Total gross profits are calculated by subtracting the total expenses from the total revenues.*	Norwegian kronor (NOK)
Cost/KG_Fish_Production= IF Slaughtered_Weight> 0 AND TIME> 525 THEN (Direct_Expense/Slaughtered_Weight) ELSE 0 *Per kg fish production cost is calculated, dividing all the accumulated costs by the total slaughtered bimass.*	Norwegian kronor per Kilogram (NOK/Kg)

Parameter Settings for the Economics Sector

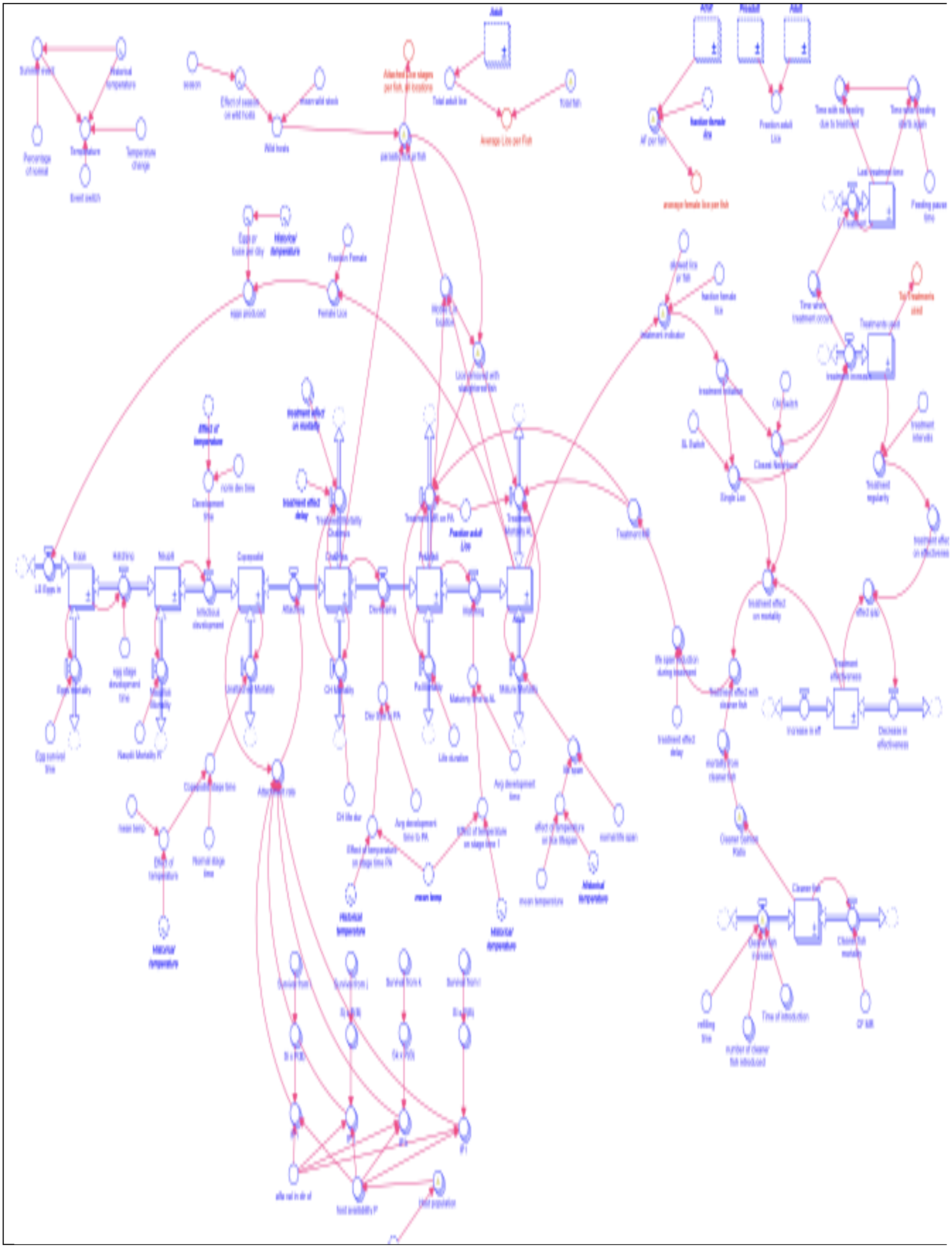
Parameter Name	**Initial Value**	**Units**
Temporary Workforce based on the Production. *Temporary workforces are calculated based on the production. It is estimated that one temporary employee is hired per 300000kg biomass production.*	300000	Kilogram per employee (Kg/Employee)
Fish Market Price *Five years Historical price data is used as per fish weight class. There are 5 different weight classes. 0.5-1Kg, 1-2Kg, 2-3Kg, 3-4Kg and 4-5Kg*	Graphical function	Norwegian Kroner per Kilogram (NOK/Kg)
Annual Cost per workforce including TAX	600000	Norwegian Kroner per year per

		employee (NOK/Year/Employee)
Feed Cost per KG	15	Norwegian Kroner per Kilogram (NOK/Kg)
Slaughtering Cost per KG	2	Norwegian Kroner per Kilogram (NOK/Kg)
Cost of Treatment per Fish	7	Norwegian Kroner per Kilogram (NOK/Kg)
Operational Fixed Workforce	15	Employees (Employees)
Number of Location	04	Unitless
Net Biomass Weight/Kg	0.86	Unitless
Days to Reset Revenues	365	Days (Days)
Days to Reset Expenses	365	Days (Days)
Grams to KG Conversion	1000	Grams per Kilogram (Grams/Kg)
Ton to KG Conversion	1000	Kilogram per Ton (Kg/Ton)
Year to Day Conversion	365	Days per year (Days/Year)

Appendix D – Picture of Production and Growth Sector



Appendix E – Picture of Lice Sector



Appendix F – Picture of Economic Sector