Fishy Business

The dynamics of the survival of wild Icelandic salmon alongside the salmon farming industry

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GEO-SD304 / System Dynamics Modelling Process

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1. Introduction

With growing world population there will be increased need for food. Fisheries are reaching their maximum potential and will not be able to meet the demand for seafood on a global scale. With a growing demand for food, a new method of producing food was started in the last century and has been growing rapidly since the start of the 21st century. That method is aquaculture, and it is believed to have the potential to bridge that gap by farming the fish in closed pens to be consumed by people around the world. This is not unsimilar from normal cattle or sheep farming, just done with fish. It has been growing rapidly since the start of the 21st century and is currently the fastest growing food-producing sector in the world (Subasinghe, Soto, & Jia, 2009).

Iceland has recently started developing salmon fish farms, and at rapid speeds. Going from under 4,000 tonnes per year to 45,000 tonnes per year between 2014 and 2021. This growth hasn't been without consequences on the nature as on August 20th, approximately 3500 salmon escaped from a pen located in Patreksfjörður, Iceland (McVeigh, 2023).

The farmed fish have already been found in the rivers in Iceland where the wild salmon spawns their eggs in late autumn and could end up reproducing with them. When wild Atlantic salmon breed with farmed salmon, their offspring develop faster and become mature at a younger age. This will lead to decreased ability to survive in the wild and reproduce in the natural environment (Vaughan, 2021).

Norway is a country that Iceland should look towards, however, not for good reasons. Norway started large scale fish farming in the 1960s (Ford R. J., 1984) and the total stock of wild salmon in Norway is expected to have halved since then. Annually, 200,000 salmon escape from their pens and roam in the sea around Norway. This is four times the current wild salmon population in Iceland. Around 71% of Norway's rivers are genetically polluted by the farmed salmon. Due to this, Norway's government decided to halt issuing new licences for fish farming and therefore the companies are now coming to Iceland (North Atlantic Salmon Fund, n.d.).

With the initial escape of 3,500 non-Icelandic salmon, they now start to enter Icelandic rivers and crossbreed with the Icelandic salmon. When an Icelandic salmon and a non-Icelandic salmon crossbreed, their offspring may not be fit to survive the environment that they're born into (Ford & Myers, 2008). Their ancestors have been in fish farming pens for many generations, bred with a single purpose: to get as big and fat in the shortest possible time. My concern is that the non-Icelandic hybrid salmon may end up taking over the whole salmon population over time, increasing the total salmon population, but when the Icelandic salmon has been diminished, the total salmon population will decrease due to the lesser survivability of the non-Icelandic salmon. To gain better understanding of this behaviour process, I will use my understanding of System Dynamics to model the structure that causes this behaviour.

Three reference modes have been made that foresee to be the result of the simulation, they can be seen in figures 1, 2 and 3. I expect the total amount of salmon to initially start increase but over time the non-Icelandic salmon will take over the salmon population in Iceland by crossbreeding and endangering the wild Icelandic salmon.

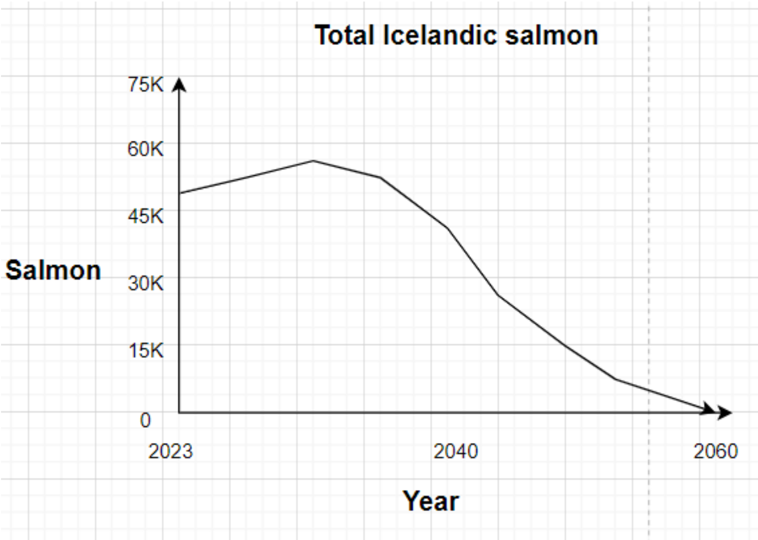


Figure 1: The reference mode for total Icelandic salmon.

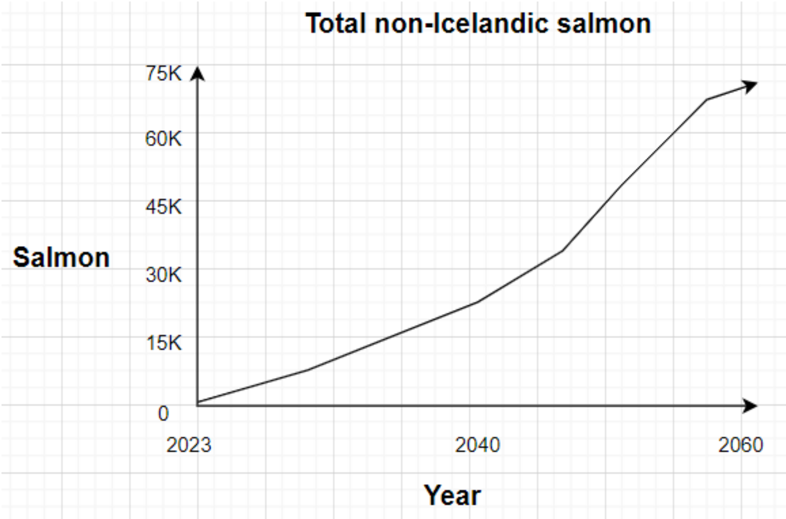


Figure 2: The reference mode for total non-Icelandic salmon.

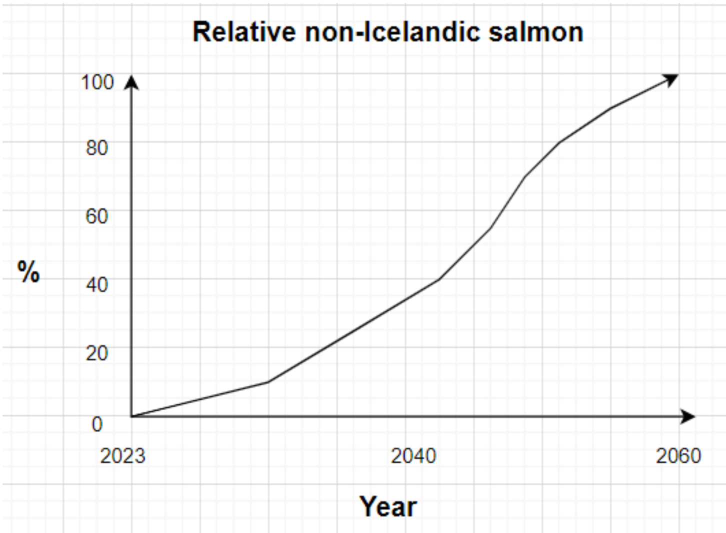


Figure 3: The reference mode for the percentage of non-Icelandic salmon in the total salmon population.

2. Model Description

To model this potential threat to the Icelandic salmon, I took some inspiration from the Bass-diffusion model where wild Icelandic and farmed non-Icelandic salmon would pair up in rivers and produce offspring called smolt who would not have the complete wild Icelandic salmon genetics. Rather, they would possess some of the genetics of salmon who have been farmed in closed fish farming pens for generations, enduring illnesses, and almost no physical activities. This salmon would be weaker and with less endurance. In the beginning of the scenario, the salmon would escape from their farming pens and start to go up rivers to mate with the wild salmon. When the tears in the fish farming nets are found, concern will build up in the public and when it reaches certain heights, the maximum allowance for salmon farming would be reduced to make sure that less salmon would escape. As the non-Icelandic salmon, abbreviated NIS salmon starts to grow in the wild, fishers get more concerned, this will further the incentive from the government to reduce the maximum allowance of fish farming. This causal mechanism has been summarised in the causal loop diagram below in figure 4.

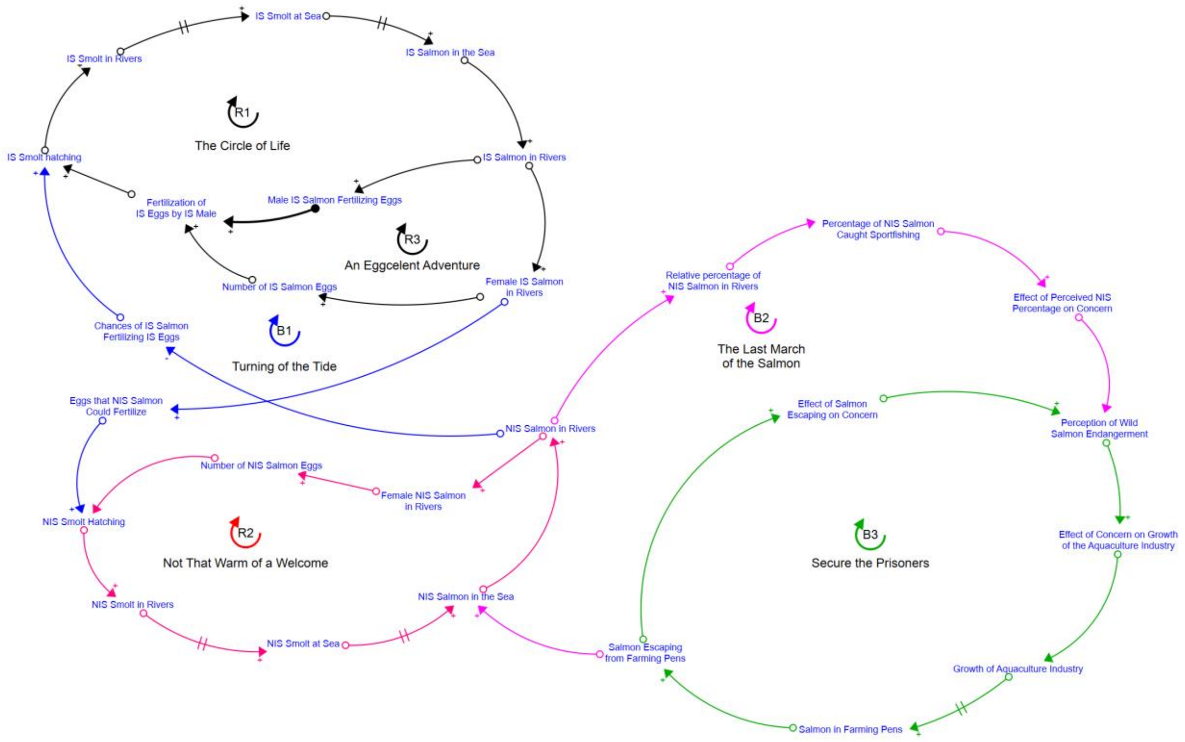


Figure 4: Causal Loop Diagram encapsulating the causal mechanism of the system.

The Circle of Life (R1) is a reinforcing loop that explains the life cycle of the male Icelandic salmon. They would enter the river and eventually fertilize the eggs from female Icelandic salmon. By this, the eggs would later hatch and smolt would come out of them. The smolt will grow up in the river it hatched in until they become old enough to start their journey to the ocean. After they enter the ocean, they will spend at least one year there until they become fully grown adults. They will then usually come back to the exact same river they hatched in to start the reproduction process once more (Thorstad, Whoriskey, Rikardsen, & Aarestrup, 2010).

An Eggcellent Adventure (R3) is a reinforcing loop that explains the same behaviour as *The Circle of Life (R1)* only that this causal loop is for the female Icelandic salmon. They follow the same process as the male salmon in that they hatch as smolt, live in rivers for some time and eventually go out to ocean. They spend at least one year in the ocean where they grow large until they re-enter the river to start to mate with other salmon. The females spawn eggs in the riverbed that will then be fertilized by the male salmon. Those eggs will hatch and female Icelandic smolt will come out of half of them (Thorstad, Whoriskey, Rikardsen, & Aarestrup, 2010).

Secure the Prisoners (B3) is a balancing feedback loop that explains the behaviour of the salmon farming industry. Initially there will be salmon safe in their farming pens. Then, in the year 2023 there will come a tear or other faulty error in the farming pens and farmed salmon will escape into the wild ecosystem. More tears in the farming pens will follow yearly with the same relative percentage of salmon escaping the farming pens. To make the salmon farming endogenous, we assume that public concern will decrease the maximum allowance of salmon being farmed, enforced by the government. When people see that farmed salmon have escaped from their farming pens they will start to grow concerned and people's perception of the wild salmon's endangerment will increase. The perception of the endangerment of the wild salmon will make the government decrease the maximum allowance of salmon farming to reduce the numbers of future farmed salmon escaping. If the perception of the wild salmon's endangerment is low, then the maximum allowance for salmon farming will increase and more salmon will be farmed in the country.

Not That Warm of a Welcome (R2) is a reinforcing loop where female non-Icelandic salmon will spawn eggs in rivers that will be fertilized by a male non-Icelandic salmon. The smolt that hatch are therefore 100% not Icelandic salmon. They follow the same process as their wild Icelandic cousins, they spawn eggs, the eggs hatch and smolt emerge, the smolt live in the river until they get old enough to go to the sea and after having living in the sea for at least one year, they go back to the river to spawn eggs.

Turning of the Tide (B1) is a balancing loop where the crossbreeding between species take place. The male non-Icelandic salmon will go up the rivers and mate with a female Icelandic salmon. The eggs will be completely Icelandic until the non-Icelandic male fertilize the eggs. Those eggs will then have genetics of salmon who has through many generations been living in salmon farming pens and bred with the sole purpose of getting big and fat in the shortest possible time. The smolt that hatch from those eggs are not as fit to survive in the wild environment as their Icelandic cousins (Ford & Myers, 2008). Some of them will survive to adulthood and start to mate with other salmon. They will then make all their offspring also non-Icelandic. This feedback loop takes the eggs from the Icelandic salmon and turns them into non-Icelandic salmon. So as there are more non-Icelandic salmon mating with Icelandic salmon, the fewer possible Icelandic offspring there will be.

3. Validation

To build confidence in the model and the simulation results, a series of tests were done. The model validation tests were introduced by Barlas in his paper called *Model validation in System Dynamics*, introduced in 1994 in the International System Dynamics Conference (Barlas, 1994).

The model structure was constructed to match the reference mode. The reference mode was built on previous experience that the Norwegian salmon stock has experienced. The wild salmon stock in Norway has decreased by half over the last 40 years, the salmon farms in Norway are believed to be the cause of the decline (Norwell, 2021). A part of that decline is the hybridization and crossbreeding between the escaped farmed salmon and the wild salmon (Norwegian Scientific Advisory Committee for Atlantic Salmon, 2022).

The data for most of the variables are taken from reliable sources, while all other parameters, such as public concern are based on my own experience. The details for my variables can be found in the model documentation in Appendix B and all parameters driven from my own experience, soft variables and table functions have undergone sensitivity analysis and can be found in Appendix C. All the model parameters show unit consistency and have a real-life meaning behind them. It is possible to expand the model further and increase the model parameters with sea lice infections and pollution that affect the survival of both types of salmon but given the time scale for the project those parameters were kept outside of the model boundary. Extreme conditions test was done for different sectors in the model that all resulted in behaviours that were expected and realistic in a real-life environment. The behaviour of the key variables did change with the different extreme condition tests but all in a manner that was realistic and expected.

4. Analysis

4.1 Baseline Scenario

Figure 5 shows the simulation result of the base model that was constructed to show similar results as the reference mode. As suspected, the simulation shows similar behaviour in two key performance indicators but not for Total NIS Salmon. However, this simulation result is realistic and valid because I overlooked one important factor when I sketched the reference modes, and that is the life expectancy of NIS salmon in wild environments is lesser than for IS salmon. So instead of showing an S-shape, it shows a curve increasing decreasingly.

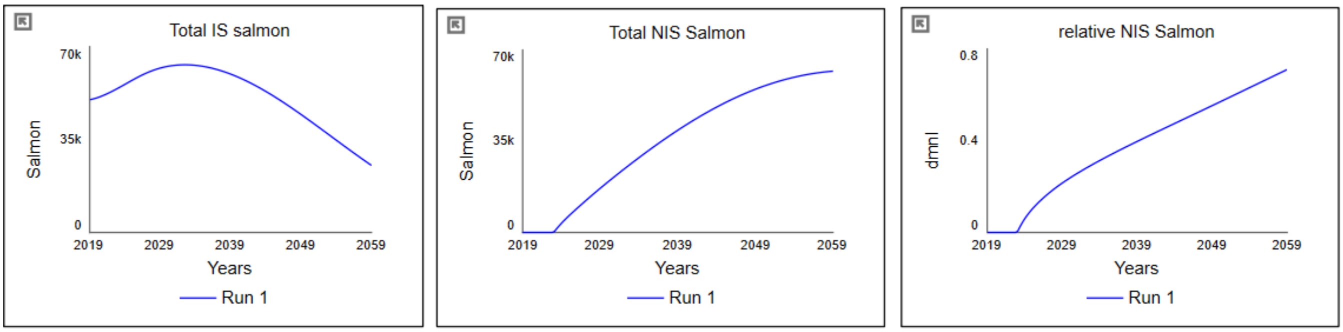


Figure 5: Key performance indicators in the baseline simulation.

The simulation starts in the year 2019, where the Icelandic salmon was alone in the seas around the country. The first escapes of the farmed salmon occur in 2023 and so for the first four years of the simulation, the Icelandic salmon thrives and grows exponentially. “The Circle of Life (R1)” and “An Eggcellent Adventure (R3)” are the driving loops in the system, as the non-Icelandic salmon hasn’t been introduced to the system yet. In the year 2023, the floodgates open from the Aquaculture section and 3,500 salmon escape into the wild environment. This is where things start to get interesting.

Immediately, the system is still dominated by the two loops, R1 and R3. The Icelandic females lay eggs that are then fertilized by the Icelandic males. Relatively little concern is being introduced to the system from the non-Icelandic salmon. After only a year, in 2024, more non-Icelandic salmon are getting through to the failures of the salmon farms through the combined efforts from the balancing “The Last March of the Salmon (B2)” and “Secure the Prisoners (B3)”.

As non-Icelandic salmon enter the system, “Turning of the Tide (B1)” starts to rapidly increase in strength. The escaped non-Icelandic males immediately start to crossbreed with the Icelandic females. Through this loop, the Icelandic salmon is making non-Icelandic offspring. At the same time, the non-Icelandic salmon are escaping into the wild from the salmon farming pens. For over five years, they are the driving loops in the system until public concern reaches the levels where the maximum allowance for salmon farming is drastically decreased. This may end up being too late to make salmon farming decisions, as the non-Icelandic salmon are already around 30% of the total salmon population at that time.

From 2028 to 2033, “Turning of the Tide (B1)” will single-handedly be the driving loop in the system. In 2033, the non-Icelandic stock has grown to the levels where it can sustain itself without “leeching” from the Icelandic salmon and now the system is controlled by “Turning of the Tide (B3)” and “Not That Warm of a Welcome (R2)”. This is only for a moment in the simulation, as “Turning of the Tide (B1)” will soon start again to assert dominance in the system, eradicating the Icelandic salmon slowly, but surely.

“Turning of the Tide (B1)” is controlling the system until the year 2056, where “The Circle of Life (R1) and “An Eggcellent Adventure (R3)” start to show some resistance. They will not increase the Icelandic salmon, but the stock will no longer decrease increasingly, but now it reached the inflection point and decrease decreasingly.

After 40 years, we reach the end of the simulation, the Icelandic salmon has dropped from 50,000 salmon to 25,300, that is almost half of the total population in just 40 years. Meanwhile, the non-Icelandic salmon has reached close to 62,000 salmon. That is 71% of the total salmon population in the country.

After seeing the results of the 40-year simulation, I decided to extend the simulation by another 20 years, until the year 2079. The key performance indicators in figure 6 show that total Icelandic salmon are almost extinct, only 868 salmon left of the species. The non-Icelandic salmon has dropped from the previous 62,000 salmon to just over 54,000 salmon. This is due to the low survivability of it and the death rate will be higher than the birth rate. The percentage of the non-Icelandic salmon in the total salmon population has reached over 95%. “Turning of the Tide (B1)” has kept on turning the eggs from the female Icelandic salmon into non-Icelandic smolt. As they are now only 5% of the total adult salmon population, there are much higher chances of the mating with a non-Icelandic salmon than another Icelandic salmon.

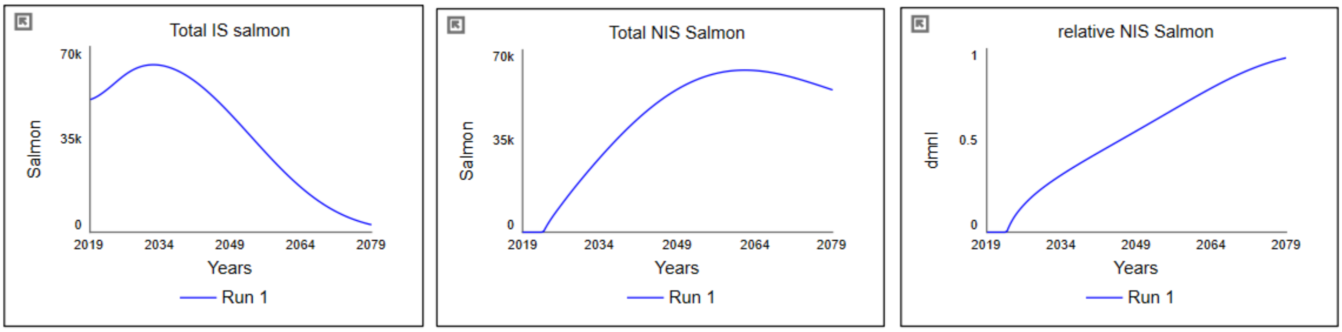


Figure 6: Key performance indicators in the baseline simulation for 60 years.

4.2 No Escapes Scenario

To see how the stock of Icelandic salmon would have fared without the aquaculture industry, I turned off the flow of farmed salmon escaping into the wild. The simulation spanned 40 years, and it looks good! In Figure 7 we see the key performance indicators, and they look very healthy for the Icelandic salmon. In a 40-year simulation, the total Icelandic salmon reached 144,000 salmon, with the reinforcing "The Circle of Life (R1)" and "An Eggcellent Adventure (R3)" driving the whole simulation. As there were no non-Icelandic salmon introduced to the system, they had no effect on the stock of Icelandic salmon, and their total numbers stayed at 0, as well as the percentage of the population.

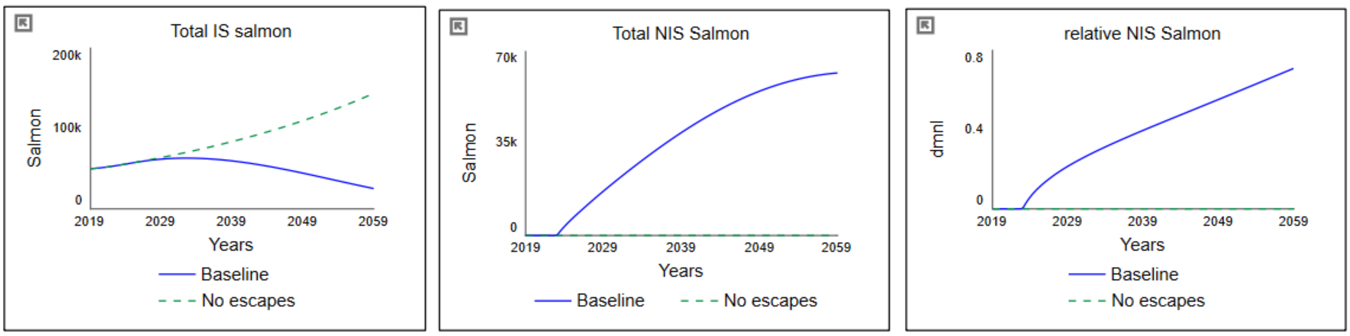


Figure 7: Key performance indicators in the "No Escapes Scenario".

4.3 Policy Implications

After seeing how the baseline simulations affected the wild Icelandic salmon, the balancing "Turning of the Tide (B1)" loop is the clear perpetrator in lessening the Icelandic salmon while at the same time, increasing the numbers of the non-Icelandic salmon. To lower the impacts of "Turning of the Tide (B1)", we must try to lessen the numbers of the non-Icelandic salmon in the system. It is unrealistic that we could somehow decide or force who the salmon are mating with in the rivers. The only way to prevent the non-Icelandic salmon from reproducing is to take them out of the system. To combat the spread of the non-Icelandic salmon, I introduced three policies:

1. Fine, I'll do it Myself: People fishing for sport would kill the non-Icelandic salmon that they catch in the rivers.
2. Government Support: Government would hire professional divers with harpoons that cover rivers and kill the non-Icelandic salmon that they find in the rivers.
3. Tighten the Rope: Improving the aquaculture farms so that they have lesser chances of failing, making sure that the farmed salmon does not escape.

4.4 Fine, I'll do it Myself

Fishing in rivers is a big sport for many Icelanders, and they love their salmon. In most rivers it is mandatory to release all the salmon that you catch to make sure that the salmon will be able to reproduce at the end of the summer. When the non-Icelandic salmon start to increase in numbers, the chances of catching them will increase. As the people in the country notice more failures in the farming pens, and sportfishers catch more non-Icelandic salmon in the rivers, they will start to grow concerned. The sportfishers would kill the non-Icelandic salmon that they catch in the rivers. They would not kill the smolt they may catch because it is incredibly difficult to tell them apart during their juvenile period. The balancing "Turning of the Tide (B1)" loop is dominating in this simulation, but it has been slowed down. Figure 8 shows the key performance indicators for this policy implementation. This would slow down the growth of the non-Icelandic salmon, ending with under 25,000 total salmon at the end of the simulation. By slowing down the growth of the non-Icelandic salmon, the Icelandic salmon grows at the same time, ending the simulation slightly under 72,000 total salmon. The non-Icelandic salmon ended as a quarter of the total salmon population. This policy does not eradicate the non-Icelandic salmon, but it can be done with almost no preparations and would add no extra cost to implement. As there are less non-Icelandic salmon in the system, the incentive to decrease the maximum allowance of fish farming is decreased. This means that the policy is punishing the taxpayer with the money the government spends while simultaneously allowing the aquaculture industry to thrive and earn more money.

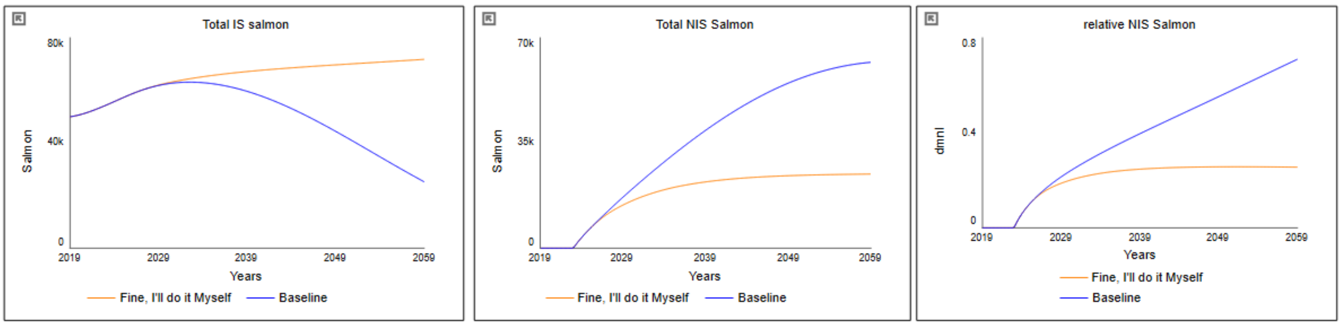


Figure 8: Key performance indicators with the "Fine, I'll do it Myself" policy active.

4.5 Government Support

As the government allowed the aquaculture industry to grow so rapidly, they must take a part of the blame for this problem. With this policy, they would hire professional divers who would swim up rivers with harpoons and kill all the non-Icelandic salmon in the rivers before they were able to mate with other salmon. From my own experience, I feel that the government would be less motivated than the sportfishers to make changes, as the fishers are the ones that have deep passion and patriotism for their salmon. Therefore, the concern threshold for the government to step in would be higher than the threshold for the fishers themselves. That means that the government would step in later than the sportfishers. The divers would cover the biggest rivers in the beginning, as they would be able to spot more salmon with less efforts. As the public concern grows and reaches its peak, the divers would start to cover more rivers, but it's impossible for them to cover all the rivers in the country. Figure 9 shows the key performance indicators with the government support policy applied. The Icelandic salmon is just below 62,000 salmon after a 40-year simulation, but we can see that it's slowly on its way down at the end of the simulation. The growth of the non-Icelandic salmon is slowed down with this policy, ending the simulation at just over 28,000 salmon and around 31% of the total salmon population. "Turning of the Tide (B1)" is still the driving loop for the simulation, but it was slowed down. This policy could be very expensive and would possibly not be seen by the government as a solution to deal with the problem. This policy deals with the same problems as the "Fine, I'll do it myself" policy in that as there are less non-Icelandic salmon in the system, the incentive to decrease the maximum allowance of fish farming is decreased, and subsequently allowing the aquaculture industry to thrive while punishing the taxpayer.

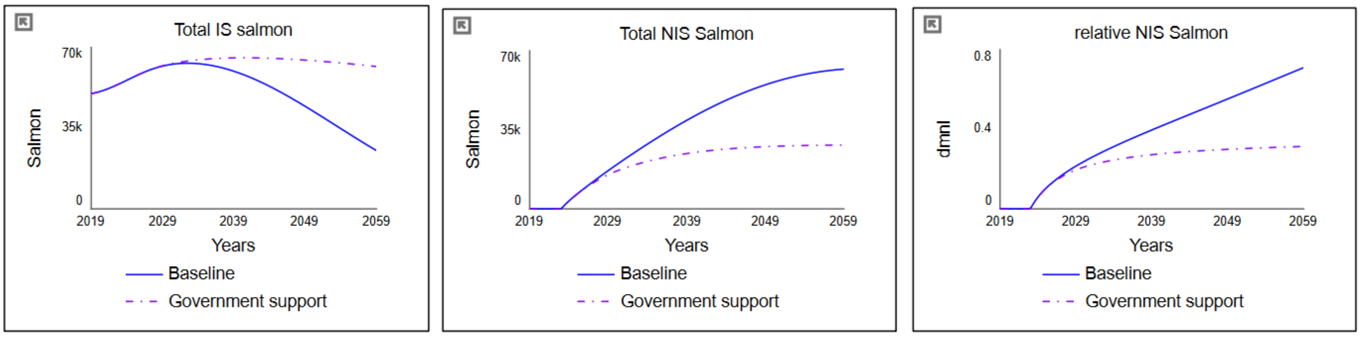


Figure 9: Key performance indicators with the "Government Support" policy active.

4.6 Tighten the Rope

The start of the problem originated in the aquaculture industry. In normal industry work, the best way to stay out of harms' way is not to wear a helmet, it is to eliminate the danger. This also applies to this system. By strengthening the farming pens and minimalizing failures, we would decrease the chances and total amount of non-Icelandic salmon that escape and enter the system. Strengthening the pens does not happen instantly, it takes time and incentive to start that process. As public concern grows, there would be more incentive to strengthen the farming. Figure 10 shows the key performance indicators for the policy. As we can see, there is almost no change in the behaviour in the system. The only noticeable change occurred when the non-Icelandic salmon were already around 50% of the total salmon population, a little late to be making some impacts.

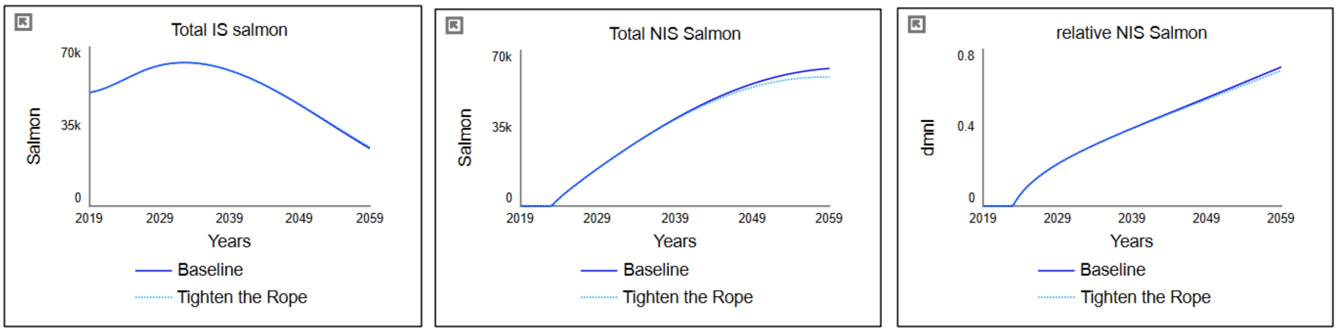


Figure 10: Key performance indicators with the "Tighten the Rope" policy active.

However, this policy could be the long-term solution for the problem if applied alongside other policies. Seen in figure 11, the policy starts to affect the system with high impacts at the later stages of the simulation. Unfortunately, the Icelandic salmon is almost extinct at that time.

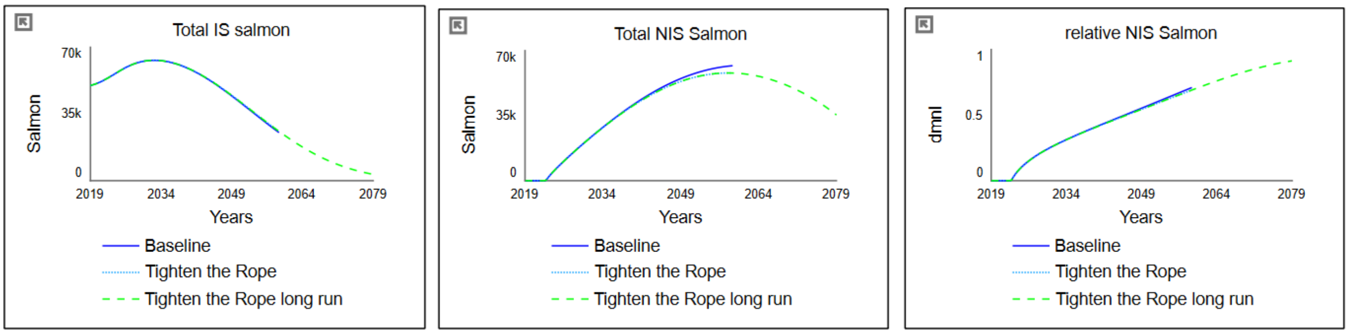


Figure 11: Key performance indicators with the "Tighten the Rope" policy active for 60 years.

4.7 All Policies Together

With all three policies brought together. “Fine, I’ll do it Myself” and “Government Support” would act as the short-term solution for the problem while “Tighten the Rope” would be in development. As seen in figure 12, all policies are working together and reaching the most optimal results of all the simulations. With all policies working together, the total Icelandic salmon at the end of the simulation stands at just under 80,000 salmon. The non-Icelandic salmon at the end of the simulation stand close to 27,000 salmon which is around 22% of the total salmon population.

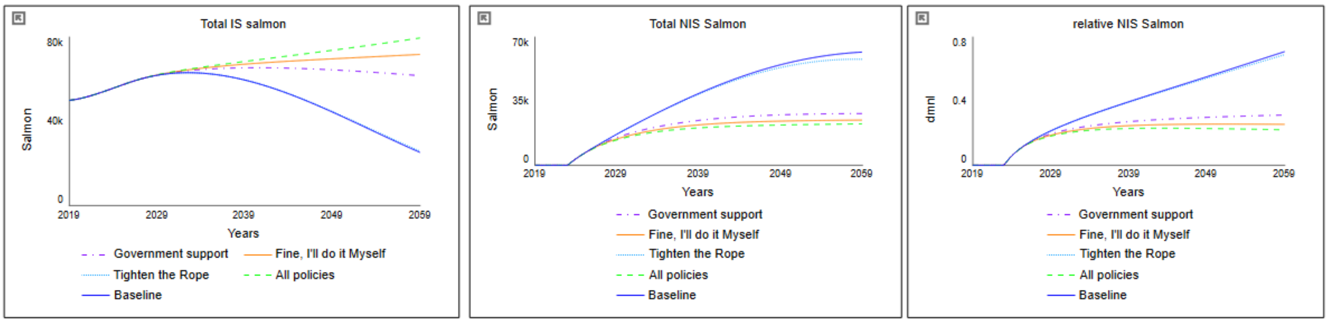


Figure 12: Key performance indicators for all the runs, including all policies working together.

To show the effectiveness of the three policies being run together, figure 13 shows the simulation of them for 200 years. The total Icelandic salmon in the year 2219 reached 1.17 million salmon, the non-Icelandic salmon are at 33,000 salmon which is just under 3% of the total salmon population. The reason for the sudden increase of the non-Icelandic salmon in figure 13 is because as the percentage of non-Icelandic salmon decreased, people started to become complacent and stop improving the farming pens, killing the fished non-Icelandic salmon and the government wouldn’t be killing the non-Icelandic salmon in the rivers. These numbers look a bit unrealistic, as the rivers are not spacious enough to have over a million salmons. There would be some stagnation from crowding effects. That could be covered with future research. Still, preventing the non-Icelandic salmon from breaking 3% in 200 years would be a remarkable achievement!

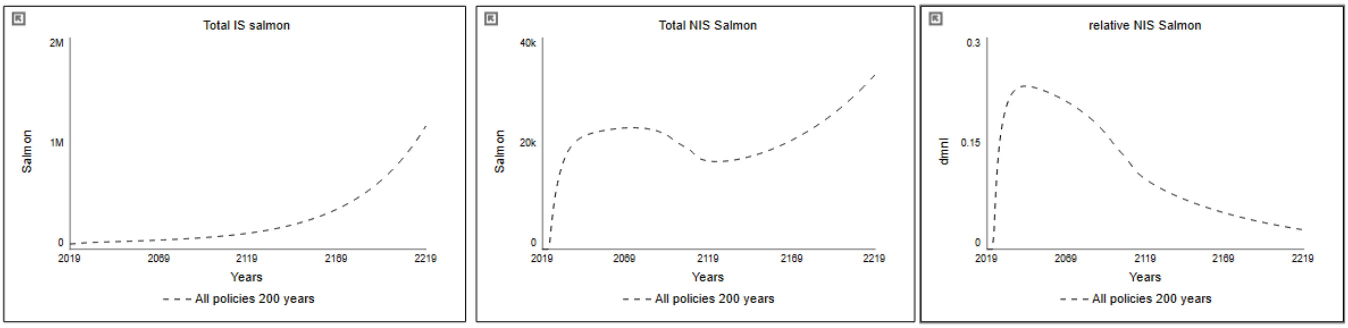


Figure 13: Key performance indicators for all policies used together for 200 years.

5. Discussion and Conclusions

To conclude, the Icelandic salmon poses serious threat if no policies would be implemented to avert the spread of the non-Icelandic salmon that escaped from their farming pens. If nothing were to be done, we would experience the critical endangerment, and possible extinction of the Icelandic salmon in our lifetime. The escaped non-Icelandic salmon would spread rapidly and due to the initial abundance of Icelandic salmon, the chances of the non-Icelandic salmon mating with them instead within their own species are high. This can be imagined like an accumulation of snowflakes that eventually start an avalanche. The non-Icelandic salmon representing the snowflakes and the overtaking of the Icelandic salmon being the avalanche.

The balancing “Turning of the Tide” loop is the most powerful loop in the system, being the loop that “converts” the stock of Icelandic salmon over to the stock of non-Icelandic salmon. In order to reduce the number of salmon being converted, the strength of the loop must be reduced, or at least the magnitude of non-Icelandic salmon able to convert. This simulation could be thought of in a similar fashion as SIR model: “Fine, I’ll do it Myself” and “Government Support” can be thought of as the quarantine policy during the COVID-19 pandemic to lessen the infections while “Tighten the Rope” policy would work as the vaccine being developed in the meantime, making considerable effect later during the simulation and prevent infections altogether. The policies tackle the spread of non-Icelandic salmon well but have the optimal and best impact when used altogether.

This dynamic system is a simulation inside a much larger dynamic system, the whole globe. Global warming is a subject that is on everyone’s mind now, and it could lead to large scale changes in the ecosystem. If the ecosystem were to change then the survival of the Atlantic salmon could be in jeopardy, especially for the non-Icelandic salmon with its lesser survivability. It could be disastrous if the non-Icelandic salmon would take over and then die out if the effects of global warming would scale up and alter the ocean’s ecosystem. Despite the possible external factors compromising the simulation in the real-world, the results from the model should not be taken with a grain of salt. This is a real problem that could end up leading to chain reactions if the salmon stock were to be completely wiped out.

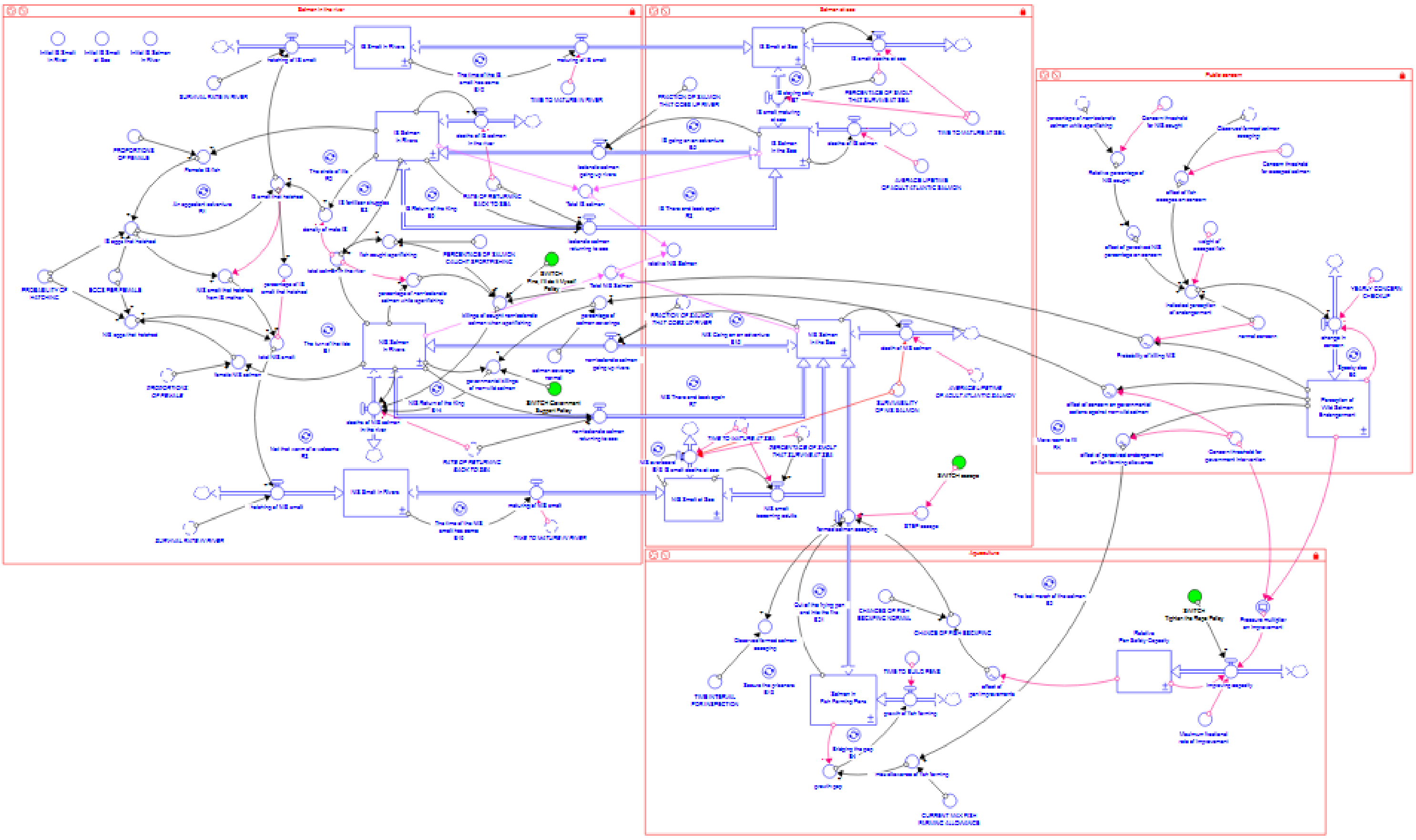
As previously stated, this model focuses solely on the genetic pollution between the two species, and other factors such as crowding effects and diseases are not considered in the simulation. The model could therefore be expanded with further research.

Below is a table with the numbers of the key performance indicators for the simulations.

	Total IS salmon	**Total NIS salmon**	**Relative NIS salmon**
Baseline	25,300	61,900	71%
Fine, I’ll do it Myself	71,800	24,700	25.6%
Government Support	71,700	28,300	31.4%
Tighten the Rope	25,900	57,900	69.1%
All Policies	79,600	22,600	22.1%

Appendix A: Model Structure

Stock and Flow Diagram



Appendix B: Model Documentation

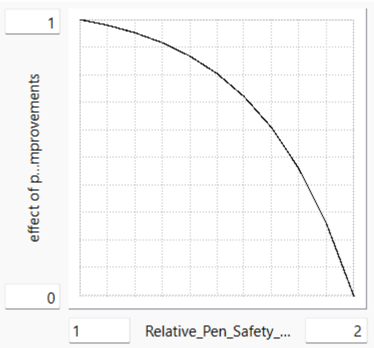
Aquaculture sector:

CHANCE_OF_FISH_ESCAPING =
CHANCES_OF_FISH_ESCAPING_NORMAL*effect_of_pen_improvements
UNITS: Per Year
DOCUMENT: The actual chances of fish escaping. It takes the normal value of the chances and multiplies the safety by the effects of improvements in the safety of the fish farming pens.

CHANCES_OF_FISH_ESCAPING_NORMAL = 0.00049
UNITS: 1/year
DOCUMENT: The yearly percentage of salmon escapes. The value is calibrated so that at the start of year 2023, 3,500 salmon will escape from the fish farming pens, as happened in Iceland.

CURRENT_MAX_FISH_FARMING_ALLOWANCE = 17166666
UNITS: salmon
DOCUMENT: Max allowed kg of fish farming in Iceland is 103,000,000 kg of salmon. The average weight of the fish that escaped the salmon pens in Patreksfjörður is 6 kg. I decided to use that as the average weight of fish farmed salmon in Iceland and used those two numbers to determine that the total amount of salmon allowed to be farmed in Iceland is 17,166,666 salmon (Gunnarsson, 2023).

effect_of_pen_improvements = GRAPH(Relative_Pen_Safety_Capacity)
Points(11): (1.000, 1.000), (1.100, 0.9796), (1.200, 0.9525), (1.300, 0.9166), (1.400, 0.8688), (1.500, 0.8053), (1.600, 0.721), (1.700, 0.609), (1.800, 0.4602), (1.900, 0.2626), ...



UNITS: dmnl
DOCUMENT: This variable shows the effect of the safety pen capacity to the chances of fish escaping. It starts at 1, when the relative pen safety capacity is at 1. As relative pen safety grows, this variable decreases towards 0, decreasing the chances of salmon escaping. When the relative pen safety grows, it decreases the chances of salmon escaping their pens, until they become 100% safe when this variable reaches 0 and no fish can escape.

growth_gap = max_allowance_of_fish_farming-Salmon_in_Fish_Farming_Pens
UNITS: Salmon
DOCUMENT: The gap between the maximum allowed fish farming and the current fish farming. If the gap is positive, then it allows the industry to grow. If the gap is negative, it forces the industry close partially.

growth_of_fish_farming = growth_gap/TIME_TO_BUILD_PENS
UNITS: Salmon/Years
DOCUMENT: The flow of growth in the fish farming industry. It flows into the stock of Salmon in Fish Farming Pens. It is calculated at each time by the growth gap for the industry, divided by the time it takes to build new fish farming facilities.

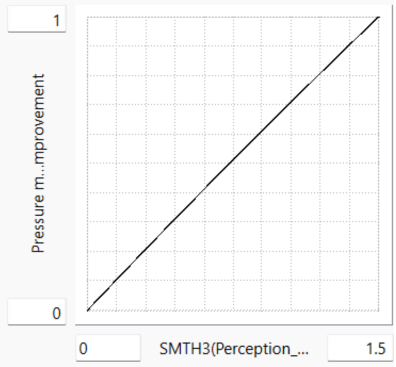
improving_capacity =
(Relative_Pen_Safety_Capacity*Maximum_fractional_rate_of_improvement*Pressure_multiplier_on_improvement)*SWITCH_Tighten_the_Rope_Policy
UNITS: dmnl/year
DOCUMENT: The flow of aquaculture pen safety capacity improving. It flows into the stock of Relative Pen Safety Capacity. The improvement at each time is the current pen safety capacity multiplied by the maximum fraction rate of improvement, they are then multiplied by the pressure multiplier on improvement. This policy is then controlled by a switch that allows this to be turned on.

max_allowance_of_fish_farming =
CURRENT_MAX_FISH_FARMING_ALLOWANCE*effect_of_perceived_endangerment_on_fish_farming_allowance
UNITS: Salmon
DOCUMENT: The actual maximum allowance for fish farming. This variable takes the public concern into considerations, where governments would either allow expansion, or force reduction in the fish farming industry. The expansion or reduction would be multiplied by the current max fish farming allowance.

Maximum_fractional_rate_of_improvement = 0.015
UNITS: dmnl/year
DOCUMENT: This variable is the maximum improvement each year that can be achieved by improving the pen safety capacity. The value of 0.015 (or 1.5%) was improvised by me. This would be 1.5% improvement on the current pen safety capacity at each time. That makes it possible to grow exponentially if there is incentive for it.

Observed_farmed_salmon_escaping =
farmed_salmon_escaping*TIME_INTERVAL_FOR_INSPECTION
UNITS: salmon
DOCUMENT: The observed salmon farming escapes each year. This is the amount of total salmon escapes that the public is informed of each year.

Pressure_multiplier_on_improvement =
GRAPH(SMTH3(Perception_of_Wild_Salmon_Endangerment/Concern_threshold_for_government_intervention,5)) {DELAY CONVERTER}
Points(11): (0.000, 0.000), (0.150, 0.1046), (0.300, 0.2081), (0.450, 0.3106), (0.600, 0.412), (0.750, 0.5125), (0.900, 0.612), (1.050, 0.7104), (1.200, 0.8079), (1.350, 0.9044), ...



UNITS: dmnl

DOCUMENT: This linear table function defines how the perception of endangerment effects the improvement of pen safety. If concern were at 0, then this variable would nullify the pen safety capacity because people wouldn't sense the need of improving pen safety. As the concern grows, this variable would increase the initiative for people to improve the pen safety so that relatively less salmon is able to escape from their farming pens. The maximum effect that this variable can take is 1, which would make the maximum fractional rate of improvement take place.

Relative_Pen_Safety_Capacity(t) = Relative_Pen_Safety_Capacity(t - dt) + (improving_capacity) * dt

INIT Relative_Pen_Safety_Capacity = 1

UNITS: dmnl

DOCUMENT: The stock of relative pen safety capacity. It is only controlled by the inflow of improving capacity. It does not have an outflow because when the safety net technology is improved, it doesn't decrease, even though there would be no additional effort in trying to improve the technology. The initial value is 1 as that is when the net safety would be normal and having no effects on the chances of fish escaping. This is a policy, and therefore not a part of the baseline scenario. It is only active when the Farming Policy is active.

Salmon_in_Fish_Farming_Pens(t) = Salmon_in_Fish_Farming_Pens(t - dt) + (growth_of_fish_farming - farmed_salmon_escaping) * dt

INIT Salmon_in_Fish_Farming_Pens = 1700000

UNITS: Salmon

DOCUMENT: The stock of total salmon that are being farmed in aquaculture farming pens. It grows by the inflow of growth of fish farming and is depleted by the flow of farmed salmon escaping. The inital value of 1.700.000 salmon is calibrated so that at the beginning of the year 2023, a total of 7.160.000 salmon are being farmed (Friðriksson, 2023).

SWITCH_Tighten_the_Rope_Policy = 1
UNITS: dmnl
DOCUMENT: The policy for the improving farming net safety. When the switch equals to 0, then the policy is not implemented. When it's at 1, it is implemented.

TIME_INTERVAL_FOR_INSPECTION = 1
UNITS: year
DOCUMENT: The time between new salmon escaping information that the public is introduced to each year. Normally, salmon escapes are events that don't happen at set times, and the public sees is informed via the news shortly after. For this model, we have yearly numbers with new information of salmon escapes.

TIME_TO_BUILD_PENS = 13
UNITS: Year
DOCUMENT: The time it takes to build new aquaculture pens if there is room for the market to grow. Calculated time to build rest of pens for current max capacity was 23 years, if it were to grow at the same rate it already is. I've decided to take away 10 years due to the industry already having been started, as I estimate that is usually the biggest hurdle in such operations.

Public concern sector:

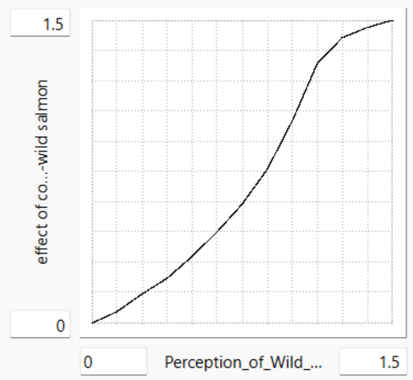
change_in_concern = (indicated_perception_of_endangerment-Perception_of_Wild_Salmon_Endangerment)/YEARLY_CONCERN_CHECKUP
UNITS: concern/Years
DOCUMENT: The bi-flow of change in concern. It flows in and out of the stock of Perception of Wild Salmon Endangerment. The value at each time is the net difference between Perception of Wild Salmon Endangerment and indicated perception of endangerment divided by yearly concern checkup.

Concern_threshold_for_escaped_salmon = 2000
UNITS: salmon
DOCUMENT: The threshold for the number of farmed salmon escaping until the public starts becoming concerned. The value of 2000 salmon was taken out of intuition from my own experience from the recent events, and how I imagine would also apply to the public.

Concern_threshold_for_government_intervention = 0.7
UNITS: concern
DOCUMENT: The threshold for concern it would have to take for the government to want to ease up on salmon farming. The high value of 0.7 was taken out of intuition by me because the industry is so profitable, and the product is always sold to markets abroad that it would have to get to considerable heights until the government would start to act.

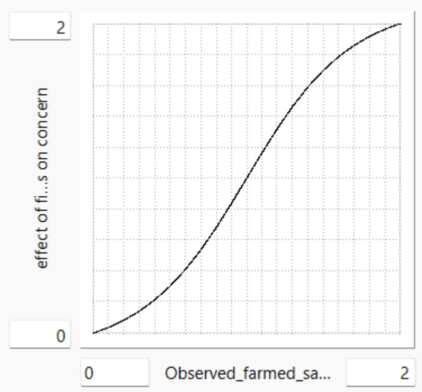
Concern_threshold_for_NIS_caught = 0.15
UNITS: dmnl
DOCUMENT: The percentage threshold for the percentage of non-Icelandic salmon to be caught by anglers until the public starts becoming concerned. The value of 0.15 (or 15%) was taken out of intuition from my own experience from the recent events and knowing how the situation unfolded in Norway.

"effect_of_concern_on_governmental_actions_against_non-wild_salmon" = GRAPH(Perception_of_Wild_Salmon_Endangerment/Concern_threshold_for_government_intervention)
Points(13): (0.000, 0.000), (0.125, 0.057), (0.250, 0.144), (0.375, 0.222), (0.500, 0.330), (0.625, 0.452), (0.750, 0.589), (0.875, 0.761), (1.000, 1.000), (1.125, 1.285), ...



UNITS: dmnl
DOCUMENT: This variable shows how the public concern would affect the killing of non-Icelandic salmon from governmental actions. If the perception of wild salmon endangerment is less than the threshold for government intervention, then the river coverage to kill non-Icelandic salmon would be less and non-Icelandic salmon would be killed as a result, leading them to be able to grow. If the concern would be the same as the threshold, then the river coverage would remain the same. If the perception of wild salmon endangerment would become higher than the threshold for government intervention then the river coverage would increase, towards the maximum of 1.5 times the normal river coverage, as it's not possible to always cover all the rivers in Iceland.

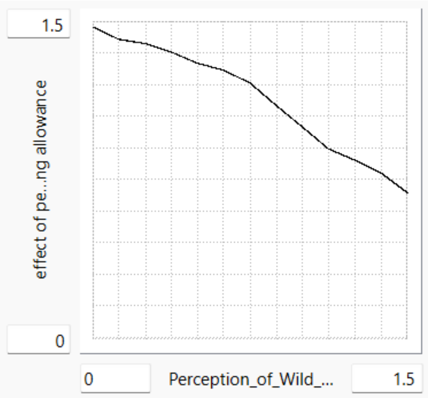
effect_of_fish_escapes_on_concern =
GRAPH(Observed_farmed_salmon_escaping/Concern_threshold_for_escaped_salmon)
Points(21): (0.000, 0.000), (0.100, 0.03696), (0.200, 0.08319), (0.300, 0.1411), (0.400, 0.2132), (0.500, 0.3019), (0.600, 0.4091), (0.700, 0.5351), (0.800, 0.6786), (0.900, 0.8356), ...



UNITS: dmnl

DOCUMENT: The effect of farmed fish escaping on concern. The numbers each year controls the value of this variable. The value of this variable can be between 0 and 2, as 2 is the value that normal concern would be multiplied by to reach 1, which is the maximum value that the stock of perception of wild salmon endangerment can take. An S-shape is in my opinion appropriate for this variable as you don't take the threat of non-Icelandic salmon too seriously, usually until it's too late, where it grows rapidly until it slows down to the maximum value of 2.

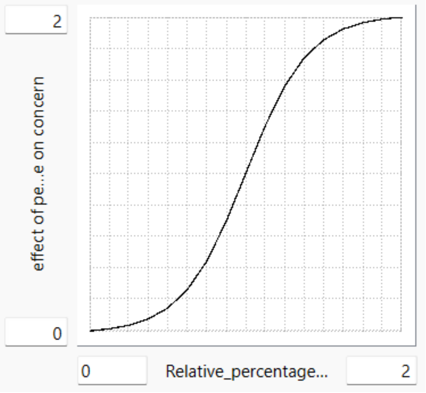
effect_of_perceived_endangerment_on_fish_farming_allowance = GRAPH(Perception_of_Wild_Salmon_Endangerment/Concern_threshold_for_government_intervention)
Points(13): (0.000, 1.473), (0.125, 1.414), (0.250, 1.394), (0.375, 1.354), (0.500, 1.301), (0.625, 1.268), (0.750, 1.208), (0.875, 1.102), (1.000, 1.000), (1.125, 0.896), ...



UNITS: dmnl

DOCUMENT: This variable shows how the public concern would affect the growth or decline of the aquaculture industry in Iceland. If the perception of wild salmon endangerment is less than the threshold for government intervention, then the industry would be allowed to grow, and the max capacity of fish farming pens would be able to grow. If the concern would be the same as the threshold, then the max fish farming allowance would remain the same. If the perception of wild salmon endangerment would become higher than the threshold for government intervention, then the max allowance of fish farming would decrease. The shape of the table function is based on my own perception of how the government would want to handle aquaculture. I believe that as most of the salmon is sold abroad, there would always be a market for it that the government and businesses would want to exploit.

effect_of_perceived_NIS_percentage_on_concern = GRAPH(Relative_percentage_of_NIS_caught)
Points(17): (0.000, 0.000), (0.125, 0.01315), (0.250, 0.03592), (0.375, 0.07581), (0.500, 0.145), (0.625, 0.2609), (0.750, 0.4421), (0.875, 0.6956), (1.000, 1.000), (1.125, 1.304), ...



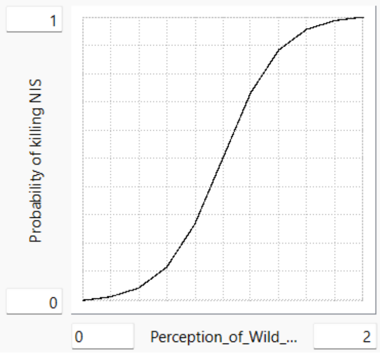
UNITS: dmnl
DOCUMENT: The effect of perceived non-Icelandic salmon caught on concern. The relative percentage of non-Icelandic salmon has control of the value of this variable. The value of this variable can be between 0 and 2, as 2 is the value that normal concern would be multiplied by to reach 1, which is the maximum value that the stock of perception of wild salmon endangerment can take. An S-shape is in my opinion appropriate for this variable as you don't take the threat of non-Icelandic salmon too seriously, usually until it's too late, where it grows rapidly until it slows down to the maximum value of 2.

indicated_perception_of_endangerment = normal_concern*((effect_of_perceived_NIS_percentage_on_concern*(1-weight_of_escaped_fish))+(effect_of_fish_escapes_on_concern*weight_of_escaped_fish))
UNITS: concern
DOCUMENT: This variable represents the concern that the people have regarding the endangerment of the wild Icelandic salmon. It values the effects of non-Icelandic salmon caught when fishing and the escapes of farmed salmon with their respective weights. That is then multiplied by the normal concern so that the value would never exceed 1.

normal_concern = 0.5
UNITS: concern
DOCUMENT: The normal concern that the average Icelander would have on potential harm to their wild Icelandic salmon. I decided to make the value at 0.5 out of my own intuition for the average Icelander after the recent fish farming incidents in Iceland, and also after learning what is happening to the wild salmon around Norway.

Perception_of_Wild_Salmon_Endangerment(t) = Perception_of_Wild_Salmon_Endangerment(t - dt) + (change_in_concern) * dt
INIT Perception_of_Wild_Salmon_Endangerment = 0
UNITS: concern
DOCUMENT: The stock of perception of the endangerment of the wild Icelandic salmon. It is controlled by the bi-flow of change in concern. The initial value of the stick is 0 as there are no non-Icelandic salmon in the sea or river systems at the start of the simulation, therefore there would be no need for concern.

Probability_of_killing_NIS = GRAPH(Perception_of_Wild_Salmon_Endangerment/normal_concern)
Points(11): (0.000, 0.000), (0.200, 0.01263), (0.400, 0.04341), (0.600, 0.1165), (0.800, 0.2676), (1.000, 0.500), (1.200, 0.7324), (1.400, 0.8835), (1.600, 0.9566), (1.800, 0.9874), ...



UNITS: dmnl
DOCUMENT: The likeliness that Icelandic anglers would be inclined to kill the non-Icelandic salmon that they catch. As long as there is any concern then there will be some anglers who would kill non-Icelandic salmon that they catch. If the concern would be double the size of normal concern, then every angler would kill every single non-Icelandic salmon that they catch. An S-shape is in my opinion the appropriate form for this table function because it counts concern into the probability of killing the non-Icelandic salmon. If the fishers catch a non-Icelandic salmon but have no concern, then they would have no inclination to kill it.

Relative_percentage_of_NIS_caught = "percentage_of_non-icelandic_salmon_while_sportfishing"/Concern_threshold_for_NIS_caught
UNITS: dmnl
DOCUMENT: This variable represents when the concern of the percentage of non-Icelandic salmon being caught by anglers starts to take effect. As long as the percentage of non-Icelandic salmon caught remains below the concern threshold, then this variable remains below 1. The value of this variable is then taken into effect with the variable named effect of perceived NIS caught.

weight_of_escaped_fish = 0.2
UNITS: dmnl
DOCUMENT: This variable represents the weights of concern from farmed fish escaping their pens in the aquaculture industry. The combined values from this variable and the weight of non-Icelandic salmon caught by anglers always equal to 1. The value of 0.2 was taken out of my own initiative as it would in my opinion weigh considerably more when you notice non-Icelandic salmon being caught by anglers than when the news report escapes of farmed fish.

YEARLY_CONCERN_CHECKUP = 1/52
UNITS: year
DOCUMENT: The rate at which the workers in the aquaculture industry do checkups on their farming pens to check if they have any tears or other abnormal failures in them. For this simulation, I have decided they do weekly checkups on their farming pens and the value would therefore be 1/52.

Salmon at sea sector:

AVERAGE_LIFETIME_OF_ADULT_ATLANTIC_SALMON = 5
UNITS: year
DOCUMENT: The average age of an adult Atlantic salmon. If a salmon reaches adulthood, he will live on average for 2-7 years. For this model, I have decided that an adult salmon will live on average for 5 years out of my intuition (Jonsson, Hansen, & Jonsson, Variation in age, size and repeat spawning of adult Atlantic Salmon in Relation to river discharge, 1991).

death_of_NIS_salmon =
NIS_Salmon_in_the_Sea/(AVERAGE_LIFETIME_OF_ADULT_ATLANTIC_SALMON*SURVIVABILITY_OF_NIS_SALMON)
UNITS: Salmon/Years
DOCUMENT: The outflow of death from the stock of NIS Salmon in the Sea. The value at each time is determined by the value of NIS Salmon in the Sea, divided with AVERAGE LIFETIME OF ATLANTIC SALMON, which is multiplied with SURVIVABILITY OF NIS SALMON. It only takes the average lifetime of an Atlantic salmon into account and not accidental fishing of it or being preyed upon in the sea.

deaths_of_IS_salmon =
IS_Salmon_in_the_Sea//AVERAGE_LIFETIME_OF_ADULT_ATLANTIC_SALMON
UNITS: Salmon/Years
DOCUMENT: The outflow of death from the stock of IS Salmon in the Sea. The value at each time is determined by dividing IS Salmon in the Sea with AVERAGE LIFETIME OF ADULT ATLANTIC SALMON. It only takes the average lifetime of an Atlantic salmon into account and not accidental fishing of it or being preyed upon in the sea.

farmed_salmon_escaping =
(CHANCE_OF_FISH_ESCAPING*Salmon_in_Fish_Farming_Pens)*STEP_escape
UNITS: Salmon/Years
DOCUMENT: The flow of farmed salmon escaping. It flows out of the stock of Salmon in Fish Farming Pens and into the stock of NIS Salmon in the Sea. It represents the total amount of farmed salmon who escape their pens at each time interval. In the beginning of the simulation, the flow is closed off and no non-Icelandic salmon is introduced to the system. At time step 4, the flow is opened with a STEP-function. The flow is calculated at each time with the total value of Salmon in Fish Farming Pens multiplied by CHANCE OF FISH ESCAPING.

FRACTION_OF_SALMON_THAT_GOES_UP_RIVER = 0.6
UNITS: 1/year
DOCUMENT: The fraction of adult salmon in the sea that goes up rivers to reproduce. The value of 0.6 is an assumption that makes sense to me.

IS_Salmon_in_the_Sea(t) = IS_Salmon_in_the_Sea(t - dt) + (IS_smolt_maturing_at_sea + icelandic_salmon_returning_to_sea - icelandic_salmon_going_up_rivers - deaths_of_IS_salmon) * dt
INIT IS_Salmon_in_the_Sea = 50000-IS_Salmon_in_Rivers
UNITS: Salmon
DOCUMENT: The stock of adult wild Icelandic salmon in the sea. It counts only the total amount of the adult wild Icelandic salmon population that is in the sea and not those who are in the rivers. It is controlled by the inflows of IS smolt maturing at sea, and Icelandic salmon returning to sea. Its outflows are deaths of IS salmon, and Icelandic salmon going up rivers. The initial value is at 31,000 salmon, that is calibrated by the estimated 50,000 salmon currently around Iceland. 19,000 of those salmon are calibrated to be in rivers at the beginning of the simulation to get rid of transient behaviour in the total numbers of the salmon (Clark, 2021).

IS_Smolt_at_Sea(t) = IS_Smolt_at_Sea(t - dt) + (maturing_of_IS_smolt - IS_smolt_maturing_at_sea - IS_smolt_deaths_at_sea) * dt
INIT IS_Smolt_at_Sea = Initial_IS_Smolt_at_Sea
UNITS: Salmon
DOCUMENT: The stock of Icelandic smolt that have entered the sea and are getting ready to become adults that take part in the reproduction process. It is fed by the inflow of maturing of IS smolt and depleted by IS smolt maturing at sea and IS smolt deaths at sea. The initial value of 33.000 was hand calibrated to get rid of transient behavior at the start of the simulation.

IS_smolt_deaths_at_sea = (IS_Smolt_at_Sea*(1-PERCENTAGE_OF_SMOLT_THAT_SURVIVE_AT_SEA))/TIME_TO_MATURE_AT_SEA
UNITS: Salmon/Years
DOCUMENT: The flow of Icelandic smolt who die after they enter the sea. It flows out of the stock of IS Smolt at Sea and multiplies the remaining fraction from the percentage of smolt that survive at sea with the stock of Icelandic smolt at sea. It is then divided by the time that it would normally take for them to grow up to adults at sea to show how many smolt die during that period.

IS_smolt_maturing_at_sea =
(PERCENTAGE_OF_SMOLT_THAT_SURVIVE_AT_SEA*IS_Smolt_at_Sea)//TIME_TO_MATURE_AT_SEA
UNITS: Salmon/Years
DOCUMENT: The flow of Icelandic smolt maturing to adults. It flows into stock of IS Salmon in the Sea. The value for the flow at each time is dependent on IS Smolt at Sea multiplied by PERCENTAGE OF SMOLT THAT LIVE TO SEE ADULTHOOD. They are then divided by TIME TO MATURE AT SEA, which is the average time for smolt to become adults after entering the sea.

NIS_Salmon_in_the_Sea(t) = NIS_Salmon_in_the_Sea(t - dt) + ("non-icelandic_salmon_returning_to_sea" + NIS_smolt_becoming_adutls + farmed_salmon_escaping - "non-icelandic_salmon_going_up_rivers" - death_of_NIS_salmon) * dt
INIT NIS_Salmon_in_the_Sea = 0
UNITS: Salmon
DOCUMENT: The stock of adult wild Icelandic salmon in the sea. It counts only the total amount of the adult wild Icelandic salmon population that is in the sea. It is increased by the inflows of "icelandic smolt entering the sea", "icelandic salmon returning to sea", and "farmed salmon escaping". Its outflows are "deaths of NIS salmon", and "non-icelandic salmon going up rivers." The initial value is 0, because there are no escaped salmon at the start of the simulation.

NIS_Smolt_at_Sea(t) = NIS_Smolt_at_Sea(t - dt) + (maturing_of_NIS_smolt - NIS_smolt_becoming_adutls - NIS_smolt_deaths_at_sea) * dt
INIT NIS_Smolt_at_Sea = 0
UNITS: Salmon
DOCUMENT: The stock of non-Icelandic smolt that have entered the sea and are getting ready to become adults that take part in the reproduction process. It is fed by the inflow of maturing of NIS smolt and depleted by NIS smolt maturing at sea and NIS smolt death at sea. The initial value is 0 as there have no non-Icelandic salmon been introduced to the system at the beginning of the simulation.

NIS_smolt_becoming_adutls =
(NIS_Smolt_at_Sea*PERCENTAGE_OF_SMOLT_THAT_SURVIVE_AT_SEA)//(TIME_TO_MATURE_AT_SEA)
UNITS: Salmon/Years
DOCUMENT: The flow of Icelandic smolt entering the sea. They are adults when they enter the sea and have spent one winter there. It flows into stock of "IS Salmon in the Sea". The value for the flow at each time is dependent on "IS eggs that hatched" multiplied by "PERCENTAGE OF SMOLT THAT LIVE TO SEE ADULTHOOD". They are then divided by "YEARS FOR SMOLT TO MATURE" to make sure that the flow takes the juvenile time of the smolt in consideration when it enters the stock.

NIS_smolt_deaths_at_sea = (NIS_Smolt_at_Sea*(1-PERCENTAGE_OF_SMOLT_THAT_SURVIVE_AT_SEA))/(SURVIVABILITY_OF_NIS_SALMON*TIME_TO_MATURE_AT_SEA)
UNITS: Salmon/Years
DOCUMENT: The flow of non-Icelandic smolt who die after they enter the sea. It flows out of the stock of NIS Smolt at Sea and multiplies the remaining fraction from the percentage of smolt that survive at sea with the stock of non-Icelandic smolt at sea. It is then divided by the time that it would normally take for them to grow up to adults at sea to show how many smolt die during that period. The time for smolt to die at sea is multiplied by the survivability of non-Icelandic salmon in wild environments because they're not as fit to survive in a wild environment after generations of being in a fish farming pen with almost no physical exercise.

PERCENTAGE_OF_SMOLT_THAT_SURVIVE_AT_SEA = 0.52
UNITS: dmnl
DOCUMENT: The percentage of smolt who will live to see adulthood after entering the sea. The either mature into adult salmon, or they die (Mills, Hadoke, Shelton, & Read, 2005).

relative_NIS_Salmon = Total_NIS_Salmon/(Total_NIS_Salmon+Total_IS_salmon)
UNITS: dmnl
DOCUMENT: The percentage of non-Icelandic salmon of the total salmon population.

STEP_escape = 0+STEP(SWITCH_escape, 2023)
UNITS: dmnl
DOCUMENT: The STEP-function that is closing off the non-Icelandic salmon from the system. At time step 2023, it opens if the switch for escaping allows it. It relies on the switch to equal 1 to perform the STEP-function. Otherwise, it remains at 0.

SURVIVABILITY_OF_NIS_SALMON = 0.5
UNITS: dmnl
DOCUMENT: The chances of an adult non-Icelandic salmon to be able to live through his average lifetime. Their survivability is lower than their wild cousins because of generations of them being farmed in small fish farming pens where they do almost no physical exercise and diseases spreading in the crowded environment. The value of 0.5 was taken as an average as the paper showed results between 10%, and 90% (Ford & Myers, 2008)

SWITCH_escape = 1
UNITS: dmnl
DOCUMENT: The switch for the farmed salmon to escape and be introduced to the system. If it is equal to 0, then it's switched off and no farmed salmon will be introduced to the system. If it's at 1, then the farmed salmon will escape and be introduced to the system.

TIME_TO_MATURE_AT_SEA = 1.5
UNITS: Year
DOCUMENT: The time it takes for smolt to mature to salmon that will start going up rivers and take part in the reproduction process. 1.5 years was taken as an average for our salmon, taking at least 1 year to grow up in the sea, but some spend more than 1 year before taking part in the reproduction process (Hutchings & Jones, 1998).

Salmon in the river sector:

deaths_of_IS_salmon_in_the_river = IS_Salmon_in_Rivers*(1-RATE_OF_RETURNING_BACK_TO_SEA)
UNITS: Salmon/Years
DOCUMENT: The flow of deaths for Icelandic salmon while they're in the rivers. It only counts for the salmon who are too exhausted to return back to the sea as they do not eat at all when they're in the rivers. Other factors such as diseases or predation will not be taken into account in this model.

deaths_of_NIS_salmon_in_the_river = NIS_Salmon_in_Rivers*(1-RATE_OF_RETURNING_BACK_TO_SEA)+("killings_of_caught_non-icelandic_salmon_when_sportfishing")+"governmental_killings_of_non-wild_salmon"
UNITS: Salmon/Years
DOCUMENT: The number of non-Icelandic salmon who die while they're in the rivers. It is calculated by the total amount of non-Icelandic rivers and multiplied by the remaining rate of salmon returning to sea. When policies are enabled, there will be added deaths from non-Icelandic salmon killings from anglers and from governmental actions.

density_of_male_IS = IS_Salmon_in_Rivers//total_salmon_in_the_river
UNITS: dmnl
DOCUMENT: The percentage of male Icelandic salmon in the total salmon population in the river. Because the gender of the salmon is presumed to be 1:1 then we can safely assume that the proportions of male Icelandic salmon to be the same as the proportions of Icelandic salmon with the total salmon population in the rivers.

EGGS_PER_FEMALE = 6000
UNITS: 1/year
DOCUMENT: The average amount of eggs that a female salmon in rivers will spawn each year (Mills, Hadoke, Shelton, & Read, 2005).

Female_IS_fish = IS_Salmon_in_Rivers*PROPORTIONS_OF_FEMALE
UNITS: Salmon
DOCUMENT: The total amount of female Icelandic salmon in rivers. It is presumed in the model that all of them will spawn eggs.

female_NIS_salmon = NIS_Salmon_in_Rivers*PROPORTIONS_OF_FEMALE
UNITS: Salmon
DOCUMENT: The total amount of female non-Icelandic salmon in the rivers. It is presumed in the model that all of them will spawn eggs.

fish_caught_sportfishing =
total_salmon_in_the_river*PERCENTAGE_OF_SALMON_CAUGHT_SPORTFISHING
UNITS: Salmon/year
DOCUMENT: The total amount of fish that are caught by anglers across the country that are fishing for sport. By catching the fish, people would observe if the rivers had a lot of non-Icelandic salmon or not.

"governmental_killings_of_non-wild_salmon" =
percentage_of_salmon_coverings*NIS_Salmon_in_Rivers*SWITCH_Government_Support_Policy
UNITS: Salmon/Years
DOCUMENT: The amount of non-Icelandic salmon that are killed each year by governmental actions. This is mainly when professionals swim up rivers with harpoons with the purpose of killing all non-Icelandic salmon that are there.

hatching_of_IS_smolt = IS_smolt_that_hatched*SURVIVAL_RATE_IN_RIVER
UNITS: Salmon/Years
DOCUMENT: The flow of fully Icelandic eggs hatching into Icelandic smolt. It takes the survivability of the smolt in rivers into account so that the smolt who wouldn't survive in the rivers are not accounted for in the stock. It flows into the stock of IS Smolt in Rivers.

hatching_of_NIS_smolt = total_NIS_smolt*SURVIVAL_RATE_IN_RIVER
UNITS: Salmon/Years
DOCUMENT: The flow of non-Icelandic eggs hatching into non-Icelandic smolt. It takes the survivability of the smolt in rivers into account so that the smolt who wouldn't survive in the rivers are not accounted for in the stock. It flows into the stock of NIS Smolt in Rivers.

icelandic_salmon_going_up_rivers =
IS_Salmon_in_the_Sea*FRACTION_OF_SALMON_THAT_GOES_UP_RIVER
UNITS: Salmon/Years
DOCUMENT: The flow of Icelandic salmon going up rivers. It represents the total amount of salmon that will take part in the reproduction process that occurs annually in rivers. It flows out of the stock of IS Salmon in the Sea and into the stock of IS Salmon in Rivers. The value of the flow at each time is determined by the number of IS Salmon in the Sea divided by FRACTION OF SALMON THAT GOES UP RIVER.

icelandic_salmon_returning_to_sea = IS_Salmon_in_Rivers*RATE_OF_RETURNING_BACK_TO_SEA
UNITS: Salmon/Years
DOCUMENT: The flow of Icelandic salmon returning to sea after partaking in the reproduction process in the rivers. It flows out of the stock of IS Salmon in Rivers and into the stock of IS Salmon in the Sea. The value of the flow at each time is controlled by the stock of IS Salmon in Rivers multiplied by RATE OF RETURNING BACK TO SEA.

Initial_IS_Salmon_in_River = 19e3
UNITS: Salmon
DOCUMENT: See "IS Salmon in Rivers"

Initial_IS_Smolt_at_Sea = 33e3
UNITS: Salmon
DOCUMENT: See "IS Smolt at Sea"

Initial_IS_Smolt_in_River = 70e3
UNITS: Salmon
DOCUMENT: See "IS Smolt in River"

IS_eggs_that_hatched = Female_IS_fish*EGGS_PER_FEMALE*PROBABILITY_OF_HATCHING
UNITS: Salmon/Year
DOCUMENT: The total amount of eggs spawned by an Icelandic female salmon that hatched each year.

IS_Salmon_in_Rivers(t) = IS_Salmon_in_Rivers(t - dt) + (icelandic_salmon_going_up_rivers - icelandic_salmon_returning_to_sea - deaths_of_IS_salmon_in_the_river) * dt
INIT IS_Salmon_in_Rivers = Initial_IS_Salmon_in_River
UNITS: Salmon
DOCUMENT: The stock of Icelandic salmon in rivers. It counts the total number of mature Icelandic salmon that goes up rivers to take part in the reproduction process. It is controlled by the inflow of "icelandic salmon going up rivers" and the two outflows of "icelandic salmon returning to sea", and "deaths of IS salmon in the river". The initial value of the stock is 19,000. It was calibrated by so that the total adult salmon wouldn't see transient behavior in the beginning of the simulation.

IS_Smolt_in_Rivers(t) = IS_Smolt_in_Rivers(t - dt) + (hatching_of_IS_smolt - maturing_of_IS_smolt) * dt
INIT IS_Smolt_in_Rivers = Initial_IS_Smolt_in_River
UNITS: Salmon
DOCUMENT: The stock of Icelandic smolt in rivers. It accumulates by the inflow of hatching of IS smolt and depleted by maturing of IS smolt. It does not take smolt that will die into account, and therefore the only outflow of the stock is the maturing of the smolt and they will eventually swim into the sea to become adults. The initial value of 70.000 was hand calibrated to get rid of transient behavior at the start of the simulation.

IS_smolt_that_hatched = density_of_male_IS*IS_eggs_that_hatched
UNITS: Salmon/Year
DOCUMENT: The amount each year of hatched eggs each year that were spawned by an Icelandic female and fertilized by an Icelandic male. It is calculated by multiplying the total Icelandic eggs that hatched by the density of Icelandic males in the rivers.

"killings_of_caught_non-icelandic_salmon_when_sportfishing" = (fish_caught_sportfishing*Probability_of_killing_NIS*"percentage_of_non-icelandic_salmon_while_sportfishing")*"SWITCH_Fine,_I'll_do_it_Myself_Policy"
UNITS: Salmon/Years
DOCUMENT: The amount of non-Icelandic salmon that are killed by anglers when they're fishing for sports. This is only enabled by the killing policy. This only counts the adult salmon because it's difficult to tell the difference between Icelandic and non-Icelandic smolt, therefore they won't be killed by anglers if they're caught by accident.

maturing_of_IS_smolt = IS_Smolt_in_Rivers/TIME_TO_MATURE_IN_RIVER
UNITS: Salmon/Years
DOCUMENT: The flow of maturing for Icelandic smolt. It represents the process for smolt to go into the sea from the moment they hatch. It flows out of the stock of IS Smolt in River and into the stock of IS Smolt at Sea.

maturing_of_NIS_smolt = NIS_Smolt_in_Rivers//TIME_TO_MATURE_IN_RIVER
UNITS: Salmon/Years
DOCUMENT: The flow of maturing for non-Icelandic smolt. It represents the process for smolt to go into the sea from the moment they hatch. It flows out of the stock of NIS Smolt in Rivers and into the stock of NIS Smolt at Sea.

NIS_eggs_that_hatched = female_NIS_salmon*PROBABILITY_OF_HATCHING*EGGS_PER_FEMALE
UNITS: Salmon/Year
DOCUMENT: The total amount of smolt that hatched after being spawned by a non-Icelandic female salmon. It does not matter if they were fertilized by an Icelandic or non-Icelandic male because they were spawned by a non-Icelandic female and are therefore counted already as non-Icelandic.

NIS_Salmon_in_Rivers(t) = NIS_Salmon_in_Rivers(t - dt) + ("non-icelandic_salmon_going_up_rivers" - "non-icelandic_salmon_returning_to_sea" - deaths_of_NIS_salmon_in_the_river) * dt
INIT NIS_Salmon_in_Rivers = 0
UNITS: Salmon
DOCUMENT: The stock of non-Icelandic salmon in rivers. It counts the total number of mature non-Icelandic salmon that goes up rivers to take part in the reproduction process. It is controlled by the inflow of "non-icelandic salmon going up rivers" and the two outflows of "non-icelandic salmon returing to sea", and "deaths of NIS salmon in the river". The initial value of the stock is 0 as we assume that there are no non-Icelandic salmon in Iceland at the beginning of the simulation.

NIS_Smolt_in_Rivers(t) = NIS_Smolt_in_Rivers(t - dt) + (hatching_of_NIS_smolt - maturing_of_NIS_smolt) * dt
INIT NIS_Smolt_in_Rivers = 0
UNITS: Salmon
DOCUMENT: The stock of non-Icelandic smolt in rivers. It accumulates by the inflow of hatching of NIS smolt and depleted by maturing of NIS smolt. It does not take smolt that will die into account, and therefore the only outflow of the stock is the maturing of the smolt and they will eventually swim into the sea to become adults. The initial value of the stock is 0 as it is assumed that all the salmon in Iceland are fully wild salmon at the beginning of the simulation.

NIS_smolt_that_hatched_from_IS_mother = IS_eggs_that_hatched-IS_smolt_that_hatched
UNITS: Salmon/Years
DOCUMENT: The amount each year of hatched eggs each year that were spawned by an Icelandic female and fertilized by a non-Icelandic male. It is calculated by withdrawing all the eggs fertilized by Icelandic males from total amount of eggs spawned by an Icelandic female, what we have left are the total amount of smolt who were spawned by an Icelandic female but fertilized by a non-Icelandic male.

"non-icelandic_salmon_going_up_rivers" = NIS_Salmon_in_the_Sea*FRACTION_OF_SALMON_THAT_GOES_UP_RIVER
UNITS: Salmon/Years
DOCUMENT: The flow of non-Icelandic salmon going up rivers. It represents the total amount of salmon that will take part in the reproduction process that occurs annually in rivers. It flows out of the stock of IS Salmon in the Sea and into the stock of IS Salmon in Rivers. The value of the flow at each time is determined by the number of IS Salmon in the Sea divided by FRACTION OF SALMON THAT GOES UP RIVER.

"non-icelandic_salmon_returning_to_sea" = NIS_Salmon_in_Rivers*RATE_OF_RETURNING_BACK_TO_SEA
UNITS: Salmon/Years
DOCUMENT: The flow of non-Icelandic salmon returning to sea after partaking in the reproduction process in the rivers. It flows out of the stock of NIS Salmon in Rivers and into the stock of NIS Salmon in the Sea. The value of the flow at each time is controlled by the stock of "IS Salmon in Rivers" multiplied by RATE OF RETURNING BACK TO SEA.

percentage_of_IS_smolt_that_hatched = IS_smolt_that_hatched//(IS_smolt_that_hatched+total_NIS_smolt)
UNITS: 1
DOCUMENT: The percentage of smolt that hatched that are 100% Icelandic.

"percentage_of_non-icelandic_salmon_while_sportfishing" = NIS_Salmon_in_Rivers//total_salmon_in_the_river
UNITS: dmnl
DOCUMENT: The observed percentage of non-Icelandic salmon when they're caught by anglers. It takes the value of NIS Salmon in Rivers and divides them by the total salmon in river to find the percentage.

PERCENTAGE_OF_SALMON_CAUGHT_SPORTFISHING = 0.65
UNITS: dmnl/year
DOCUMENT: The percentage of fish in rivers that are presumed to end up being fished for sport. In the model it is presumed that all fish that are caught will be released again, and that being caught would have no effect on their life in the rivers. The number was calibrated from angling numbers from the year 2023 and divided by the presumed total number of Atlantic salmon around Iceland (Skúlason, 2023).

percentage_of_salmon_coverings = salmon_coverage_normal*"effect_of_concern_on_governmental_actions_against_non-wild_salmon"
UNITS: 1/year
DOCUMENT: The percentage of salmon that would be covered by governmental actions. As concern grows higher, the government would be inclined to cover more salmon than normal.

PROBABILITY_OF_HATCHING = 0.006
UNITS: dmnl
DOCUMENT: The decimal value of likeliness that each egg laid by a salmon is going to end up hatching (Mills, Hadoke, Shelton, & Read, 2005).

PROPORTIONS_OF_FEMALE = 0.5
UNITS: dmnl
DOCUMENT: The proportions of female salmon in the total salmon population. It is presumed that salmon hatch with their gender proportions to be 1:1.

RATE_OF_RETURNING_BACK_TO_SEA = 0.75
UNITS: 1/year
DOCUMENT: The rate of which salmon will return to sea after spawning season. Not all salmon return to the sea as they are too exhausted from the spawning process. They do not eat when they dwell in the rivers, where they are for many months (Jonsson, Jonsson, & Hansen, Partial segregation in the timing of migration of Atlantic salmon of different ages, 1990).

salmon_coverage_normal = 0.3
UNITS: 1/year
DOCUMENT: The normal amount of salmon rivers that would be covered if the governmental killings policy were to be put in place. This counts for the percentage of salmon that would be under river coverage because they would normally cover the largest salmon rivers to begin with. 30% of salmon coverage doesn't translate to 30% river coverage because rivers hold different amounts of salmon.

SURVIVAL_RATE_IN_RIVER = 0.08
UNITS: dmnl
DOCUMENT: The percentage of smolt that survive in rivers and make it to the stage at which they're ready to go to the sea where they will grow (Mills, Hadoke, Shelton, & Read, 2005).

"SWITCH_Fine,_I'll_do_it_Myself_Policy" = 1
UNITS: dmnl
DOCUMENT: The policy for the killing of non-Icelandic salmon caught by anglers. When the switch equals to 0, then the policy is not implemented. When it's at 1, it is implemented.

SWITCH_Government_Support_Policy = 1
UNITS: dmnl
DOCUMENT: The policy for the killing of non-Icelandic salmon by governmental actions. When the switch equals to 0, then the policy is not implemented. When it's at 1, it is implemented.

TIME_TO_MATURE_IN_RIVER = 3
UNITS: year
DOCUMENT: The average time that smolt spend in rivers before they go into the ocean to mature into adult salmon. The value of 3 is taken from me as an average (Mills, Hadoke, Shelton, & Read, 2005).

Total_IS_salmon = IS_Salmon_in_the_Sea+IS_Salmon_in_Rivers
UNITS: Salmon
DOCUMENT: The total amount of Icelandic salmon, both in sea and in rivers.

Total_NIS_Salmon = NIS_Salmon_in_the_Sea+NIS_Salmon_in_Rivers
UNITS: Salmon
DOCUMENT: The total amount of non-Icelandic salmon, both in sea and in rivers.

total_NIS_smolt = NIS_smolt_that_hatched_from_IS_mother+NIS_eggs_that_hatched
UNITS: Salmon/Years
DOCUMENT: The total amount of smolt that hatched each year that are not 100% Icelandic. This includes smolt that have one Icelandic parent.

total_salmon_in_the_river = IS_Salmon_in_Rivers+NIS_Salmon_in_Rivers
UNITS: Salmon
DOCUMENT: The total amount of salmon that are in the rivers at each time.

Appendix C: Model Testing Results

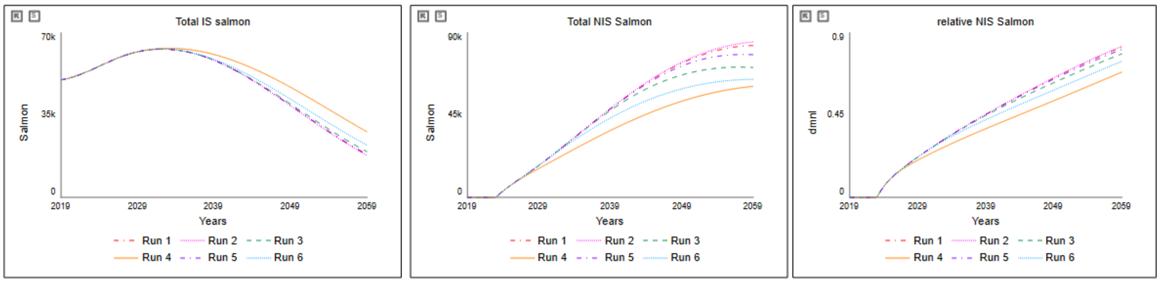
Integration Error Test

The model was tested for 1/128, 1/64, 1/32, with both Euler and Runge-Kutta 4 integration methods. The simulations with DT as 1/128 and 1/64 showed similar results whereas 1/32 showed behavioural changes in the system. As the shortest adjustment time in the model is 1/52 years (i.e., 1 week), the minimum DT should be 1/64 with Euler to prevent integration errors.

Sensitivity Analysis

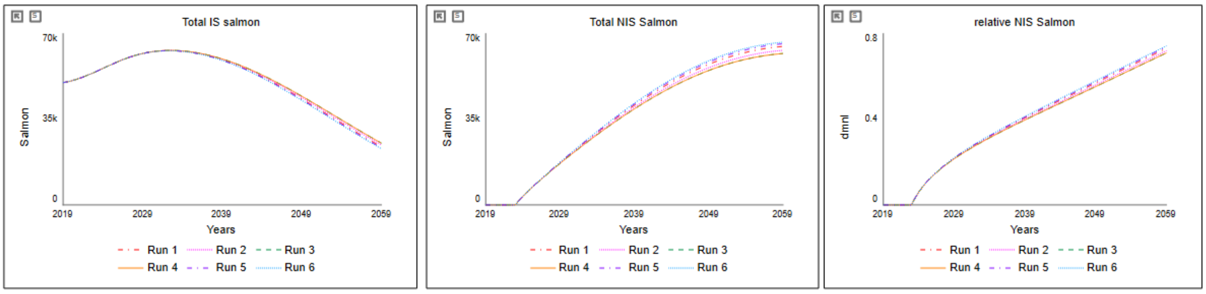
The sensitivity of the model was tested on the baseline scenario. It was done with Stella's Model Analysis Tools feature. Each test was done with uniform distribution and Latin Hypercube sampling. Six runs were configured for each test. Given the numerous amounts of variables in the model, only table functions and variables who show high sensitivity will be documented below.

Concern threshold for NIS caught (range: 0 – 1)



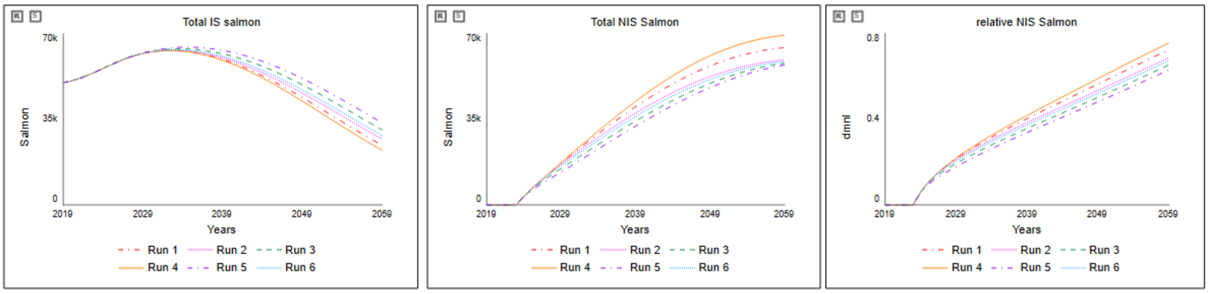
The model is only numerically sensitive to this parameter, the behaviour remains the same. That is expected as the balancing "The last march of the salmon" loop (B3) starts becomes effective at a much later time as this parameter increases. This means that the concern will not start to grow until at a much later time. The concern for the survival of the wild salmon affects the max allowance of farming practices until there would be too many non-Icelandic salmon in the system, caused by the reinforcing "Not that warm of a welcome" loop (R3) increasing the rate of non-Icelandic salmon hatching and growing to adult salmon, and the balancing "The turn of the tide" loop (B1) lessening the likelihood of Icelandic salmon spawning, therefore decreasing the percentage of Icelandic salmon in the system. Confidence in this parameter should not be diminished as the current value of 0.15 may even be higher than the real-life value would be. This is the maximum value that it should be at, coming from experience as an Icelander, whom this concern is relevant to.

Concern threshold for escaped salmon (range: 100 – 10,000)



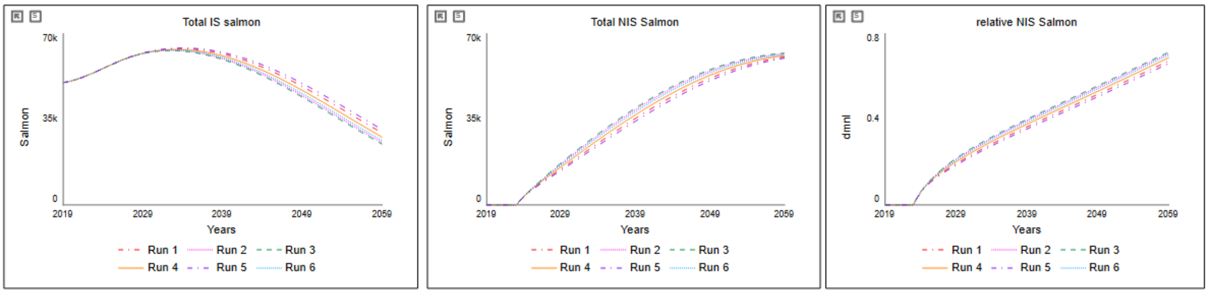
The model is only numerically sensitive to this parameter when it comes to the farmed salmon escaping. The effect of the concern would come in effect too late to stop the spread of the non-Icelandic salmon, thus the behaviour of the model would remain the same. Otherwise, the model is not significantly sensitive to this parameter.

Concern threshold for government intervention (range: 0 – 1)



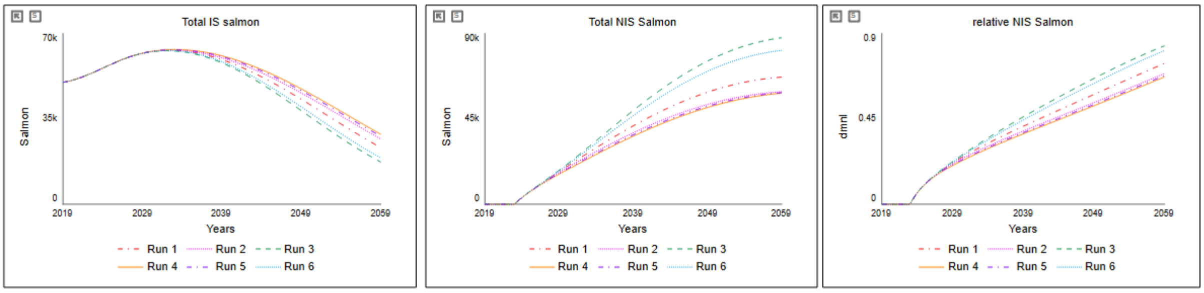
This is a soft variable whose baseline scenario value was taken from my own experience. The simulation results show numerical changes with extreme values in simulation, and so the variable is only slightly sensitive.

Weight of escaped fish (range 0 – 1)



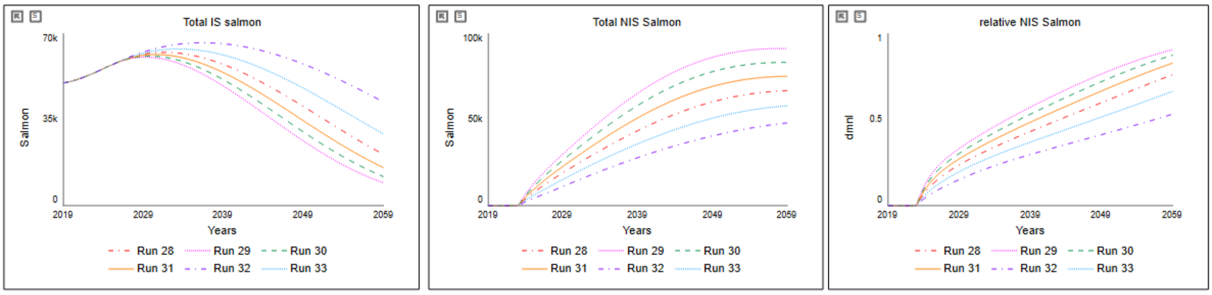
The model is not sensitive to this variable. The total weights of escaped fish and percentage of non-Icelandic salmon caught during sportfishing will equal to 1. This means that if this variable equal 0, the weight of concern from non-Icelandic salmon caught would equal 1, and vice-versa. The confidence in this variable should not be diminished, as from my own experience the concern weight of actual caught non-Icelandic salmon in the rivers would weigh more than reported escapes from fish farms.

NORMAL CONCERN (range: 0 – 1)



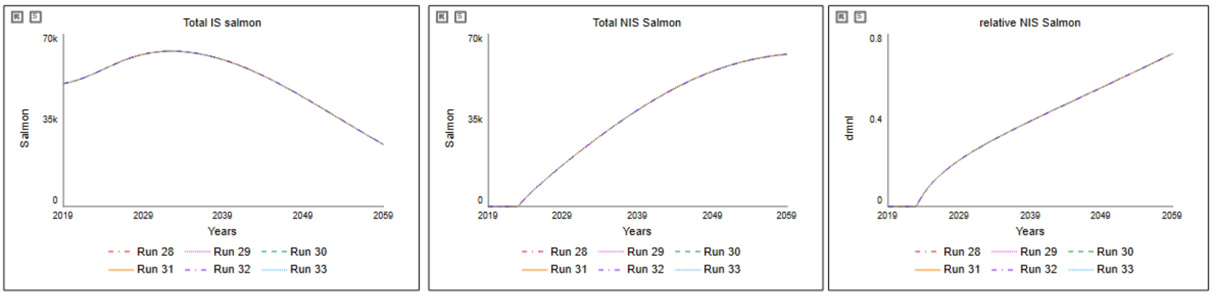
The model is only showing numerical change but with big gaps between the values. The model shows no behavioural sensitivity and therefore this variable is only considered slightly sensitive.

CHANCES OF FISH ESCAPING NORMAL (range: 0.00025 – 0.001)



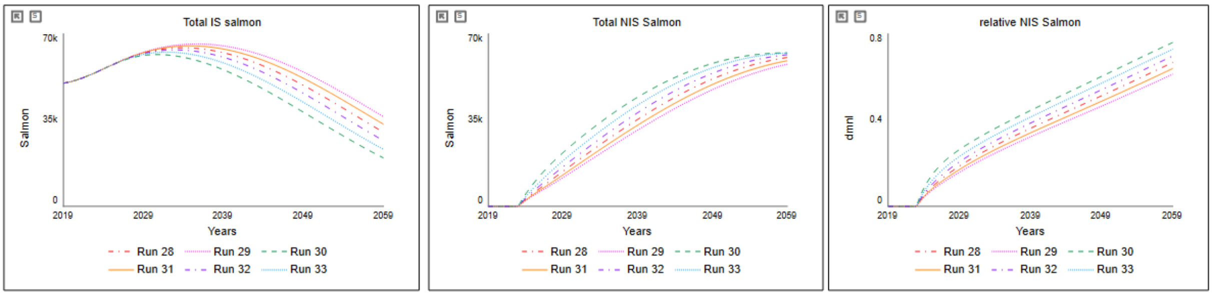
The model simulation only shows numerical sensitivity to this parameter, but the number differences are considerable. The model does not however show behavioural change. Therefore, the model is only slightly sensitive.

TIME INTERVAL FOR INSPECTION (range: 0.5 – 2)



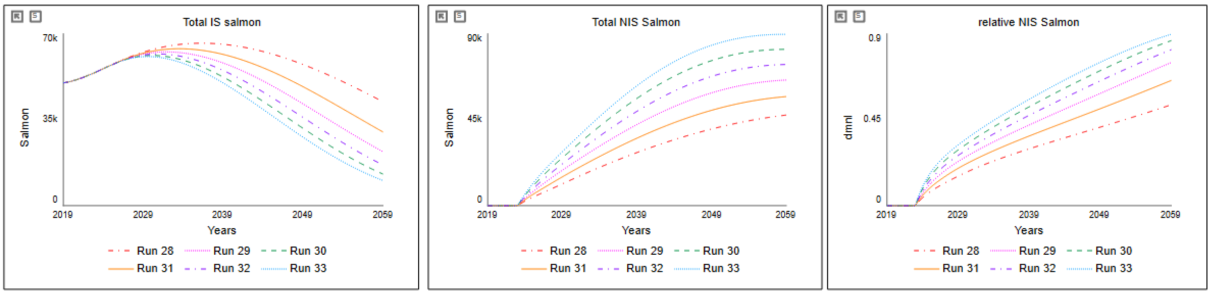
The model is not sensitive to this parameter at all.

TIME TO BUILD PENS (range: 6 -26)



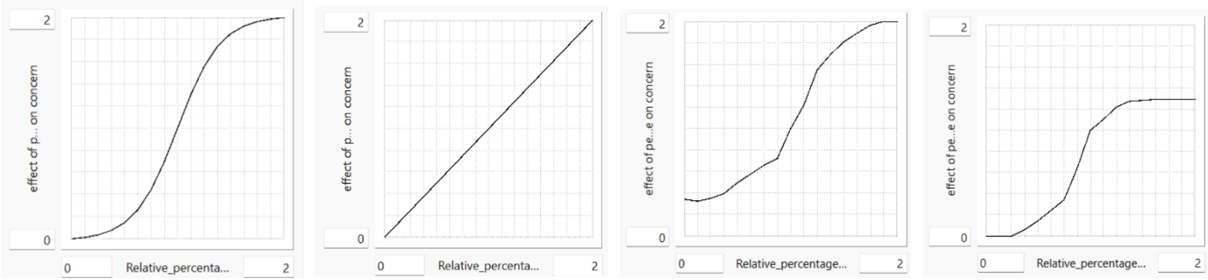
The model shows only slight numerical sensitivity to this parameter but no behavioural. It is therefore not sensitive.

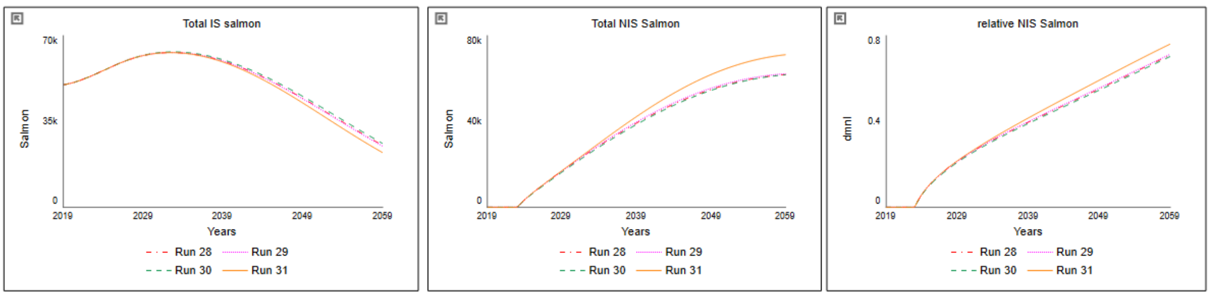
CURRENT MAX FISH FARMING ALLOWANCE (range: 8,500,000 – 34,000,000)



The model shows only numerical sensitivity to this parameter, and no behavioural sensitivity is observed. The model is not sensitive to this parameter.

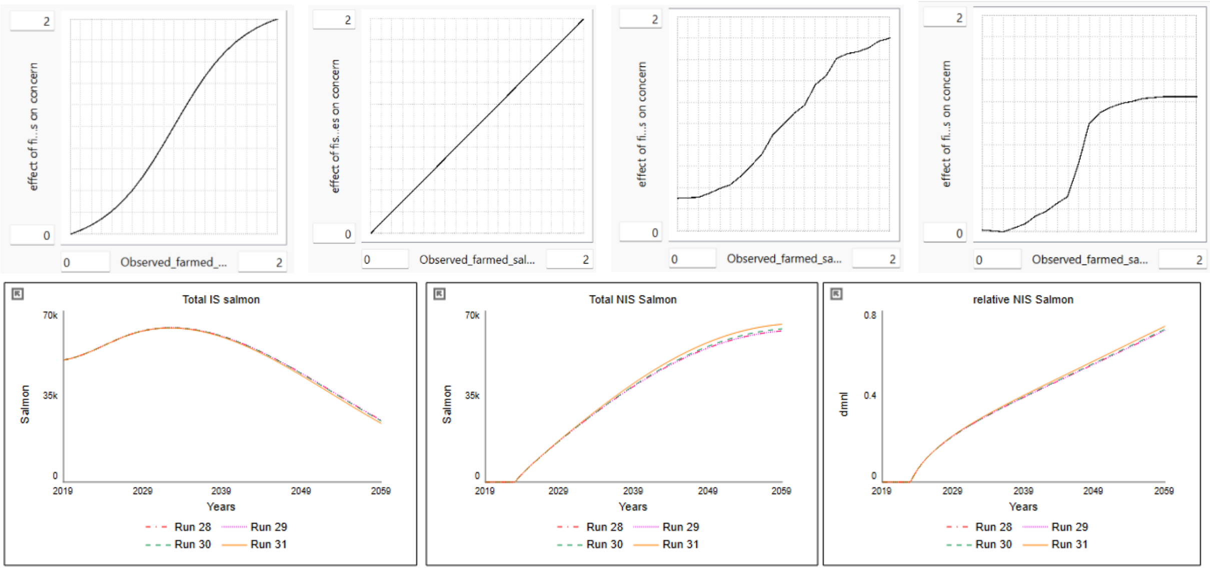
Effect of perceived NIS percentage on concern





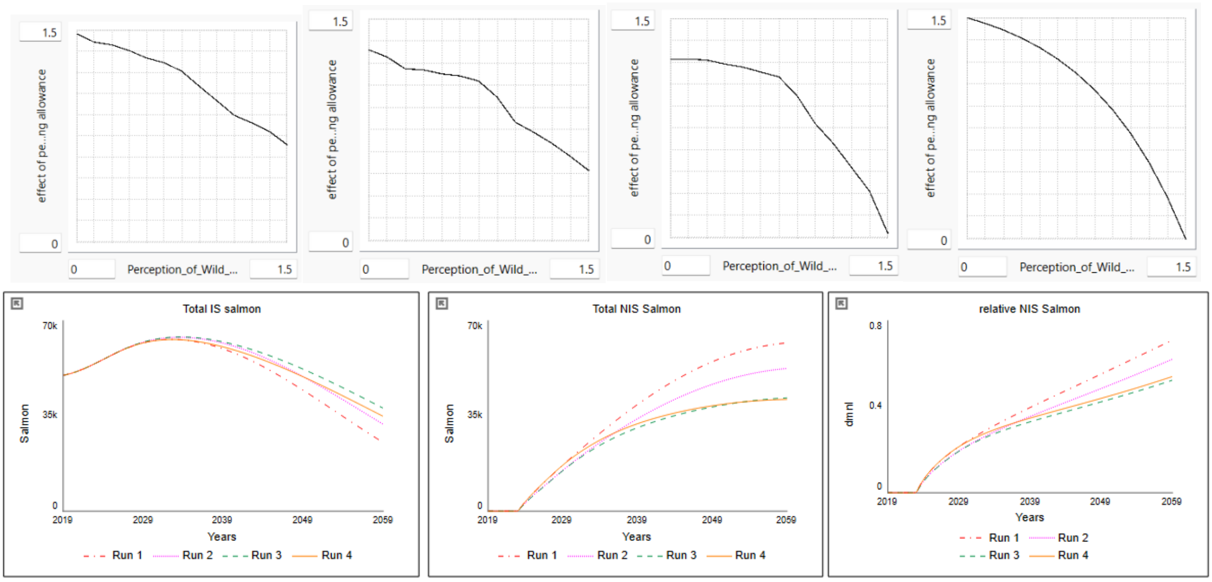
The model shows only slight numerical sensitivity to this table function. It is therefore not sensitive to this parameter.

Effect of fish escapes on concern



The model barely shows numerical sensitivity to this parameter and shows no behavioural sensitivity. It is not sensitive.

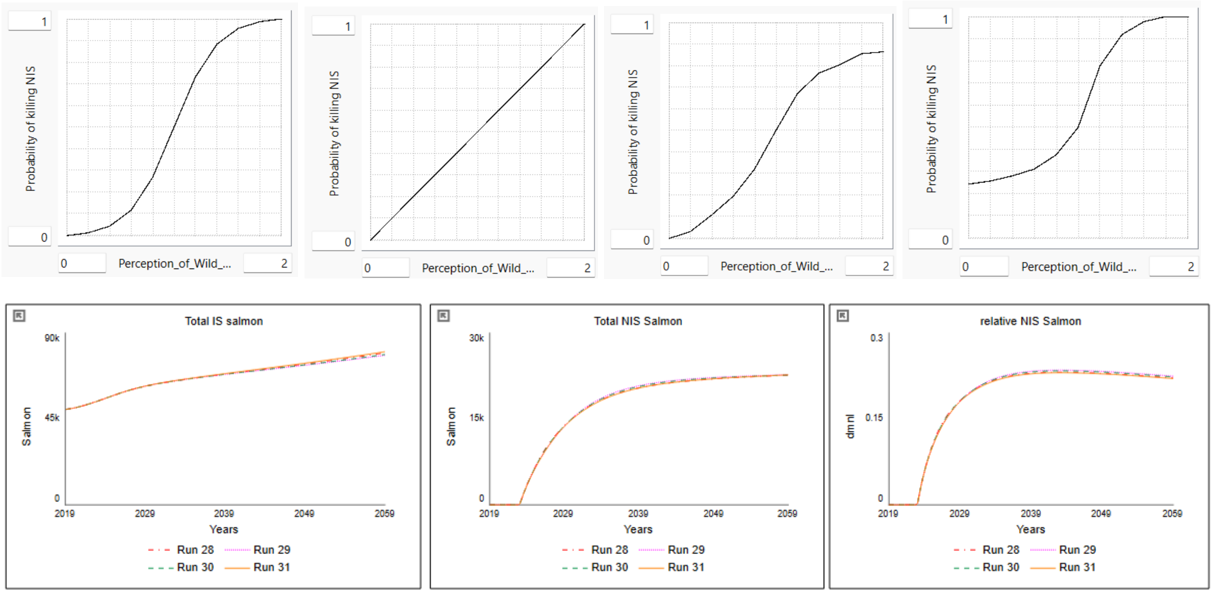
Effect of perceived endangerment on fish farming allowance



The model shows only numerical sensitivity to this parameter and no behavioural sensitivity, it is therefore not sensitive to this parameter.

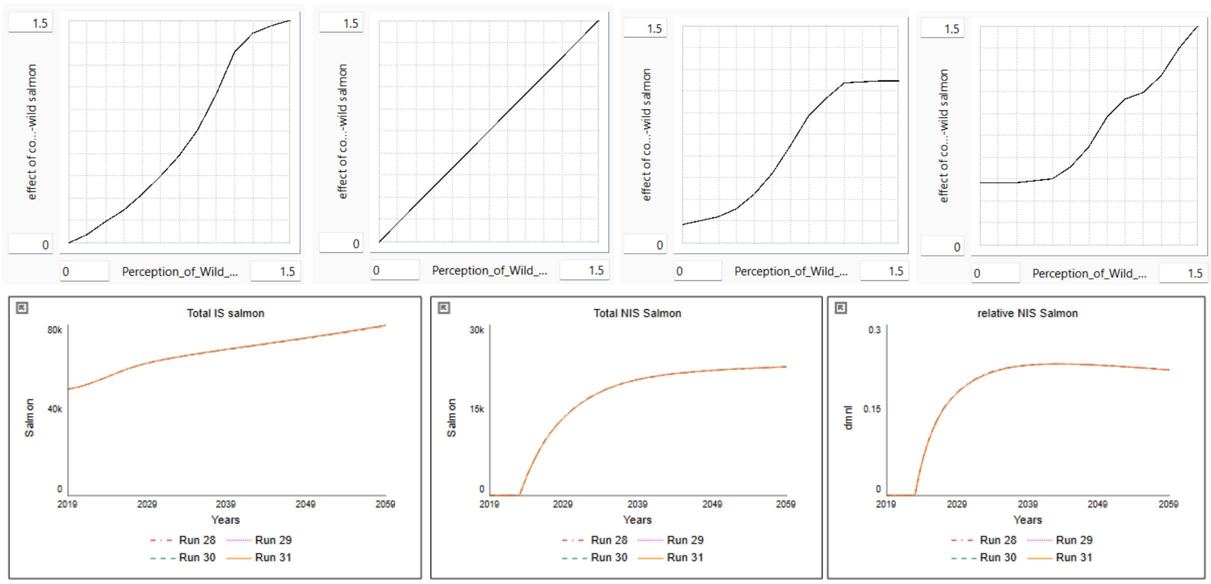
The following table functions are only active during certain policies, all policies will be active during the sensitivity analysis.

Effect of perceived endangerment on fish farming allowance



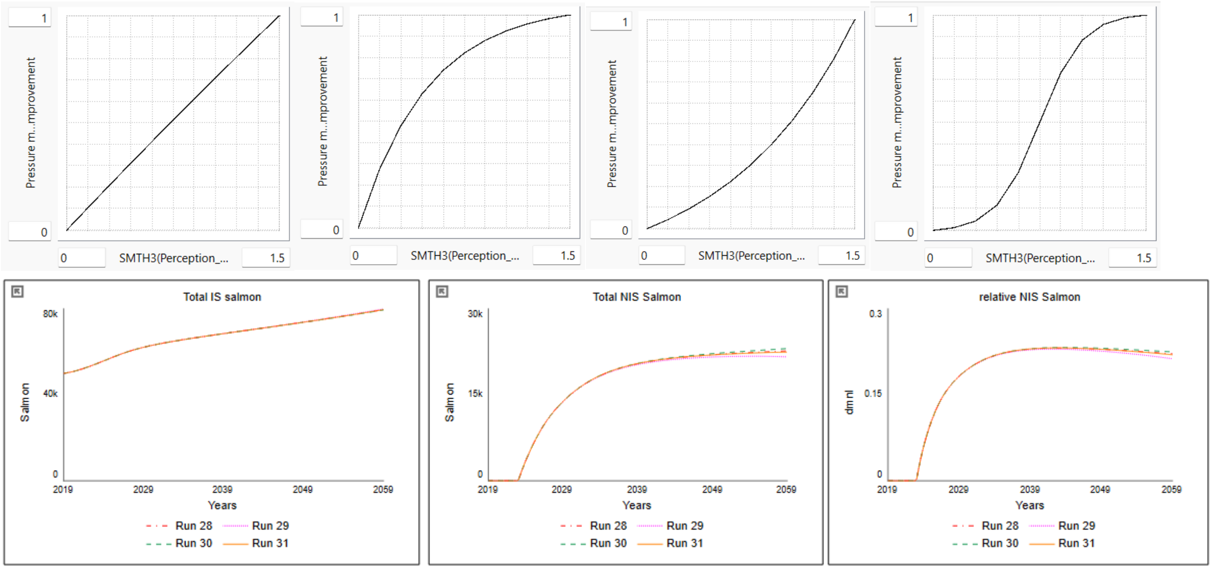
The model is not sensitive to this parameter.

Effect of concern on governmental actions against non-wild salmon



The model is not sensitive to this parameter

Pressure multiplier on improvement



The model is not sensitive to this parameter.

Appendix D: Simulation Experiment Report

Modelling Software: Stella Architect 3.4.1
Integration Method: Euler's Integration Method
DT: 1/64
Time Units: Years
Simulation Start Time: 2019
Simulation End Time: 2059

Baseline Scenario:

SWITCH escape: 1
SWITCH I'll do it Myself Policy: 0
SWITCH Government Support Policy: 0
SWITCH Tighten the Rope Policy: 0

No escapes Scenario:

SWITCH escape: 0
SWITCH I'll do it Myself Policy: 0
SWITCH Government Support Policy: 0
SWITCH Tighten the Rope Policy: 0

Policy Implementations:

Fine, I'll do it Myself:

SWITCH escape: 1
SWITCH I'll do it Myself Policy: 1
SWITCH Government Support Policy: 0
SWITCH Tighten the Rope Policy: 0

Government Support:

SWITCH escape: 1
SWITCH I'll do it Myself Policy: 0
SWITCH Government Support Policy: 1
SWITCH Tighten the Rope Policy: 0

Tighten the Rope:

SWITCH escape: 1
SWITCH I'll do it Myself Policy: 0
SWITCH Government Support Policy: 0
SWITCH Tighten the Rope Policy: 1

All Policies Together:

SWITCH escape: 1
SWITCH I'll do it Myself Policy: 1
SWITCH Government Support Policy: 1
SWITCH Tighten the Rope Policy: 1

References

Barlas, Y. (1994). Model validation in System Dynamics. *System Dynamics: Methodological and Technical Issues*, 1-10.

Clark, A. (2021, November 18). *Iceland In Focus: Wild Salmon, A Kayaker And An Environmental Awakening*. Retrieved from Forbes: https://www.forbes.com/sites/ashoka/2021/11/18/iceland-in-focus-wild-salmon-a-kayaker-and-an-environmental-awakening/?sh=3e3038a9250a

Ford, J. S., & Myers, R. A. (2008). A Global Assessment of Salmon Aquaculture Impacts on Wild Salmonoids. *PLoS Biology, 6(2), e33*, 411-417.

Ford, R. J. (1984). Norwegian Salmon and Trout Farming. *Marine Fisheries Review, Volume 46*, 44-47.

Friðriksson, E. Ö. (2023, September 16). *Mun villtur lax lifa af árásina?* Retrieved from Veiðar: https://veidar.is/mun-villtur-lax-lifa-af-arasina/

Gunnarsson, K. H. (2023, August 21). *Kvígindisdalur: gat á kví*. Retrieved from BB: https://www.bb.is/2023/08/kvigindisdalur-gat-a-kvi/

Hutchings, J. A., & Jones, M. E. (1998). Life history variation and growth rate thresholds for maturity in Atlantic salmon, Salmo salar. *Canadian Journal of Fisheries and Aquatic Sciences 55(S1)*, 22-47.

Jonsson, N., Hansen, L. P., & Jonsson, B. (1991). Variation in age, size and repeat spawning of adult Atlantic Salmon in Relation to river discharge. *Journal of Animal Ecology 60*, 937-947.

Jonsson, N., Jonsson, B., & Hansen, L. P. (1990). Partial segregation in the timing of migration of Atlantic salmon of different ages. *Animal Behaviour, 40(2)*, 313-321.

McVeigh, K. (2023, September 30). *Thousands of salmon escaped an Icelandic fish farm. The impact could be deadly.* Retrieved from The Guardian: https://www.theguardian.com/environment/2023/sep/30/thousands-of-salmon-escaped-an-icelandic-fish-farm-the-impact-could-be-deadly

Mills, D., Hadoke, G., Shelton, R., & Read, J. (2005). *Atlantic Salmon Facts.* Perth: Woods of Perth Limited.

North Atlantic Salmon Fund. (n.d.). *A disaster in Norway*. Retrieved from North Atlantic Salmon Fund: https://nasf.is/en/norway/

Norwegian Scientific Advisory Committee for Atlantic Salmon. (2022). *Status of wild Atlantic Salmon in Norway 2022.* Trondheim: Digital document.

Norwell, F. (2021, November 24). *Atlantic salmon added to Norwegian list of threatened animals*. Retrieved from The Local: https://www.thelocal.no/20211124/atlantic-salmon-added-to-norwegian-list-of-threatened-animals

Skúlason, E. (2023, November 14). *Næst lélegasta sumarið í hálfa öld*. Retrieved from Morgunblaðið: https://www.mbl.is/frettir/veidi/2023/11/14/naest_lelegasta_sumarid_i_halfa_old/

Subasinghe, R., Soto, D., & Jia, J. (2009). Global aquaculture and its role in sustainable development. *Reviews in Aquaculture 1*, 2-9.

Thorstad, E. B., Whoriskey, F., Rikardsen, A. H., & Aarestrup, K. (2010). Aquatic Nomads: The Life and Migrations of the Atlantic Salmon. *Atlantic Salmon Ecology*, 1-32.

Vaughan, A. (2021, December 22). *Breeding with farmed fish is changing the life cycle of wild salmon*. Retrieved from NewScientist: https://www.newscientist.com/article/2302512-breeding-with-farmed-fish-is-changing-the-life-cycle-of-wild-salmon/

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