The Next Generation of Canadian Salmon*

The Effects of the Commercial Fishing Industry on Spawning Rates

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Using the NuSEDS dataset and Catch Estimates for the Pacific Region Commercial Salmon Fishery dataset provided by the Government of Canada, we investigate the effects of commercial fishing on the reproductive capacity of Canadian Salmon. Along with that, we can infer how much of the change in spawn rates can affect future populations, and whether stocking programs have been able to mitigate population decline. This paper discusses the impact of direct human intervention in the form of commercial fishing, aiming to highlight the importance in proper management and control in the fishing industry in alignement with changes in the environment by predicting spawning trends of future generations.

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*Code and data are available at: https://github.com/prajogt/canadian_salmon_spawn.git .

1 Introduction

The declining trend in Canadian salmon runs, as observed by many avid anglers and supported by empirical data ("State of Pacific Salmon" 2024), serves as the focal point of this paper. Once thriving waterways have experienced a significant reduction in salmon populations, posing challenges not only for recreational anglers but also for the fishing industry, a vital component of Canadian exports and numerous livelihoods, particularly in coastal regions. Due to this significance to many Canadians, it is important to investigate the decline in salmon runs, highlighting the importance of understanding and addressing these challenges that are faced in the effort to safeguard future salmon generations.

This paper will focus on commercial fishing trends, ocean climate trends, and spawning rates over the last decade, using datasets and fisheries statistics provided through the Government of Canada's open data portal. In particular, the NuSEDS (New Salmon Escapement Database System) provides key insights on spawn records and abundance estimates for freshwater streams and tributaries, with statistics provided by Fisheries and Oceans Canada providing detail on the amount of fish landed or released through commercial fishing methods by species. Through this data we discover the potential human-induced drivers of salmon population change including factors such as over fishing and artificial breeding. In identifying the critical areas for repair and reform, we aim to explore potential mitigation strategies and management plans with the goal of restoring salmon populations and promoting sustainable fishing practices, protecting this key resource. Preserving healthy salmon populations is not only essential for maintaining biodiversity and ecosystem balance but also for meeting demand required of this industry, both in labour and in product.

Through information gathered from these datasets, we were able to verify correlations between the frequency of fishing and the salmon population, as well as the previous years salmon population and artificial breeding practices affect on future generations. However, although these are significant factors, they do not account for all the change that is seen throughout the years. Salmon population's fluctuation cannot be fully explained by these human factors alone, which means there must be some other factors that are not described in this data that should be investigated.

This paper will introduce the data and models we used to analyze these themes and trends, explaining why features and datasets were chosen and how they are relevant to the research topic. The models we create will use commercial fisheries' catch estimates and past years artificial and natural spawn success respectively as the estimands to predict salmon populations. Then the paper will present our findings and their implications for future salmon generations observed in the models that were created as well as in the data. We will conclude by discussing the weaknesses and future steps that could be made to further improve on this research.

2 Data

The data used in this paper was provided by the Government of Canada through their Open Government Portal, published by Fisheries and Oceans Canada. This portal provided other datasets relating to salmon health / population, however, the datasets selected are consistently updated and provide relevant as well as historical data that is useful when researching yearly trends which salmon populations are due to the fact that future populations are largely impacted by the success of each year's spawn.

2.1 Spawn

For information regarding the populations of Canadian Salmon in the Pacific region, the *New Salmon Escapement Database System (NuSEDS)* ("NuSEDS-New Salmon Escapement Database System" 2024) was used to retrieve the quality and health of the Salmon population. This data is not only used to measure the populations but other health and success measures that certain area salmon have. These observations are made during the spawning season for salmon (from September - November), recording the amount of salmon that have come to spawn in a certain waterbody. As it is not possible for those wildlife officials to individually count each salmon that enters a waterway at any time during the day, an estimated count was made based on the abundance of salmon currently present during the observation.

The database provides salmon spawning observations starting from 1920's, but population numbers were not recorded / provided until 1979. As such, rows not providing population numbers were not considered. In addition, for each model, specific features were necessary to create the model, and the original dataset was split into two models, each only containing the entries that include relevant information.

Table 1: NuSEDS Data on Spawning Population

Area	Name of Waterbody	Year	Species	Natural Adult Spawners	Natural Jack Spawners	Total Return To River
29I	15 MILE CREEK	2022	Sockeye	171	0	NA
29I	25 MILE CREEK	2022	Sockeye	413	0	NA
6	AALTANHASH RIVER	2022	Chum	90	0	NA

Area	Name of Waterbody	Year	Species	Natural Adult Spawners	Natural Jack Spawners	Total Return To River
6	AALTANHASH RIVER	2022	Pink	5100	0	NA
7	ADA COVE CREEK	2022	Chum	190	0	NA
7	ADA COVE CREEK	2022	Pink	100	0	NA

Table 2: NuSEDS Data on Broodstock and Population

Area	Name of Water-body	Year	Species	Adult Broodstock Removals	Jack Broodstock Removals	Other Re-movals	Total Return To River
25	BURMAN RIVER	2022	Chinook	303	0	0	1438
16	CHAPMAN CREEK	2022	Chum	30	0	0	262
16	CHAPMAN CREEK	2022	Coho	33	0	0	263
25	CONUMA RIVER	2022	Chinook	1861	20	748	15849
25	CONUMA RIVER	2022	Chum	3403	0	0	5312
25	CONUMA RIVER	2022	Coho	257	0	0	1070

The most important part of this dataset that we consider is the spawning salmon population observed at various waterways as shown in Table 1. We then also consider the broodstock removal statistics in Table 2, which is the amount of salmon that were removed for the purposes of artificial breeding. These salmon's progeny are later released back into the wild.

Variables for both Table 1 and Table 2:

Waterbody + Area + Year:

- This defines the waterbody and the general management area that this observation came from, and what year that observation was made. I have provided the map that shows the actual geographical area that an area code signifies.

Species:

- This defines the species of salmon that the observation was made for. Observations were made for Sockeye, Chum, Pink, chinook, Coho, Steelhead, Atlantic, and Kokanee salmon, but only observations for the more common salmon species were made. (Sockeye, Chum, Pink, Chinook, and Coho) These are the salmon that make up the vast majority of the sport and the commercial market, which is the focus of this paper, and why the other salmon observations were not considered.

Total Return to River:

- This defines the total amount of salmon of that species that was observed in that waterbody, being number of natural spawners + number of non-natural spawners (fish released / cultivated by the government to support salmon population). For Table 1, an N/A value indicates that only natural spawners were observed.

Variables for Table 1:

Natural Adult Spawners:

- These are the amount of salmon observed that have reached maturity.

Natural Jack Spawners:

- These are fish that have matured at an early age, and are much smaller than the adult spawners. When the value is N/A this indicates that no jacks were not observed.

Variables for Table 2:

Adult Broodstock Removals:

- Similarly to the spawning population data, these are the amount of mature salmon that were removed from the waterbody for the purposes of breeding.

Jack Broodstock Removals:

- Similarly to the spawning population data, these are the amount of jack salmon that were removed from the waterbody for the purposes of breeding.

Other Removals:

- These are the amount of salmon that were removed from their natural environment by humans for other reasons (not broodstock) which were not defined by the dataset.

2.2 Catch

For information regarding the salmon caught in commercial fisheries, the *Pacific Region Commercial Salmon Fishery In-season Catch Estimates* (Canada 2023) was used. This data comes from the Fishery Operations System (FOS) which serves as the primary database for Fisheries and Oceans Canada's (DFO) Pacific Region Commercial Salmon Logbook program, established in 1998 and mandated fleet-wide participation by 2001. This program compels commercial salmon fishers to log daily catch and effort data in harvest logbooks, subsequently reporting it to DFO via service providers within specified deadlines. However, certain personal information provided by fishers is protected and inaccessible. Fishery Managers utilize this reported data, alongside additional sources like overflights, to compute in-season catch estimates. Its important to note that this dataset omits data from test fishing, recreational fishing, or First Nations harvest.

Table 3: Commercial Salmon Fishing Catch Estimates from 2005 - 2022 from Gill Net Fisheries

Year	Management Area	Vessel Count	Boat Days	Sockeye Kept	Sockeye Released
2005	1	0	0	0	0
2005	2	19	145	0	0
2005	3	460	3968	131511	0
2005	4	115	199	35	0
2005	6	196	1396	976	0
2005	7	72	276	78	0

Table 4: Commercial Salmon Fishing Catch Estimates from 2005 - 2022 from Seine Net Fisheries

Year	Management Area	Vessel Count	Boat Days	Sockeye Kept	Sockeye Released
2005	2	8	16	0	0
2005	3	53	436	49728	0
2005	5	12	31	0	2457
2005	6	84	589	21577	0
2005	7	17	32	0	0
2005	8	43	222	0	0

Table 5: Commercial Salmon Fishing Catch Estimates from 2005 - 2022 from Trolling Fisheries

Year	Management Area	Vessel Count	Boat Days	Sockeye Kept	Sockeye Released
2005	1	48	565	100	1036
2005	2	18	206	0	46
2005	3	25	114	0	19
2005	6	26	316	0	208
2005	7	7	33	0	46
2005	8	6	24	0	100

This dataset is provided in three parts, separated by the type of commercial fishing that was being tracked. The three types being: Gill nets, Seine nets, and Trolling.

Gill Nets

- These are vertical panels of netting suspended in the water by a float line and a weighted line. Fish swimming into the net become entangled by their gills as they attempt to pass through the mesh. Gill nets are often set in a stationary position and left for a period of time before retrieval.

Seine Nets

- Seine nets are large, horizontal nets deployed from the side of a vessel. They typically have floats along the top edge and weights along the bottom to create a wall of netting that can be drawn in a circular motion to encircle fish. Once the fish are contained within the net, it is hauled in and the catch is retrieved.

Trolling

- Trolling involves trailing baited fishing lines behind a moving vessel. The lines are attached to fishing rods or reels and are drawn through the water at varying depths and speeds. This method allows fishermen to target specific species of fish by adjusting the depth and speed of the trolling lines.

Understanding the type of fishing method used is crucial because each method has different impacts on salmon populations. For example:

- Gill nets are known for their high selectivity, catching fish primarily by their gills. However, they can also unintentionally catch non-target species and may lead to bycatch issues.
- Seine nets are effective for catching large quantities of fish in a single haul, but they may have a significant impact on fish habitat and can result in the incidental capture of non-target species.

- Trolling is often considered a more sustainable fishing method compared to nets because it allows for the release of non-target species and reduces habitat damage. However, it can still have localized impacts on salmon populations if not properly managed.

By categorizing the dataset based on the type of commercial fishing method, we can better understand the specific impacts of each method on salmon populations and inform fisheries management decisions accordingly.

For each of Table 3, Table 4, Table 5, we consider the following variables:

Year + Management Area:

- Similarly to Table 1, this signifies the year and area the catch estimates were made for. However in this case the management area is different to the area mentioned prior. It also refers to a region, however this time it refers to the area that a fish was caught in.
- Regarding this field, it was originally intended to be used to match up certain fishing regions to certain spawning regions. However, since it is not guaranteed or even expected that salmon stay close to their spawning grounds during the open fishing season, these area fields were not used in this matter. They do still have value that is not used in this report, as will be mentioned in the discussion section.

Vessel Count:

- This measures the amount of vessels fishing in a certain management area in the year.

Boat Days:

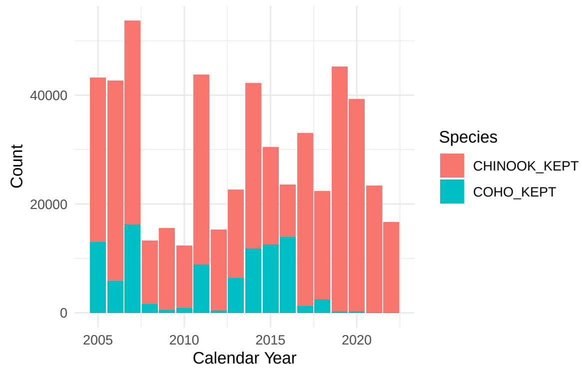
- This measures the total amount of days that each vessel was fishing in that management area. For instance if there were two vessels fishing for the same two days each, that would be 4 boat days.

Salmon Species Kept:

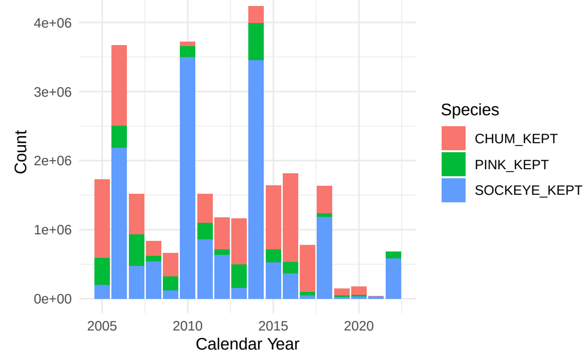
- These are the amount of salmons of that particular species indicated in the column name were kept from that management area in that year.
- Although Table 3, Table 4, and Table 5 only show sockeye kept, the catch estimates for all other salmon species are also present, they were omitted here due for simplicity.

Salmon Species Released:

- These are the amount of salmons of that particular species indicated in the column name were caught but not kept and released back into the water from that management area in that year.
- Although Table 3, Table 4, and Table 5 only show sockeye kept, the catch estimates for all other salmon species are also present, they were omitted here due for simplicity.

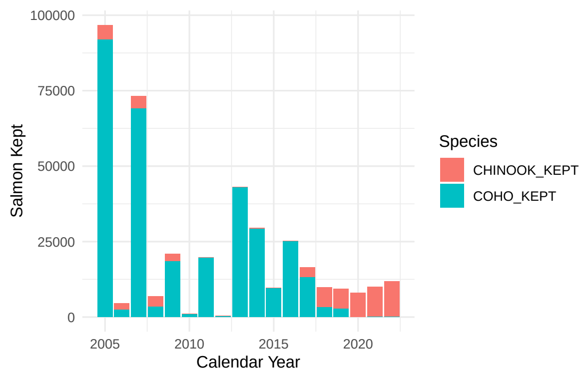


(a) Coho and Chinook

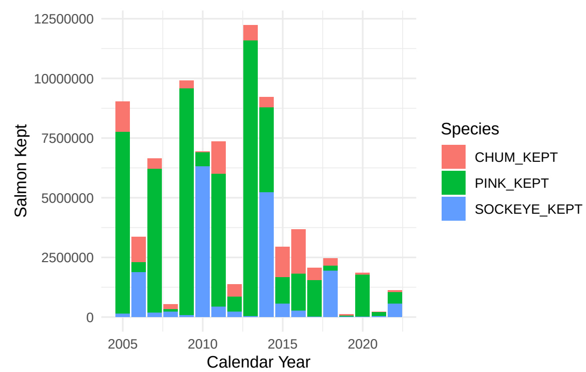


(b) Chum, Pink, and Sockeye

Figure 1: Salmon Catch Data from 2002-2022 (Gill)

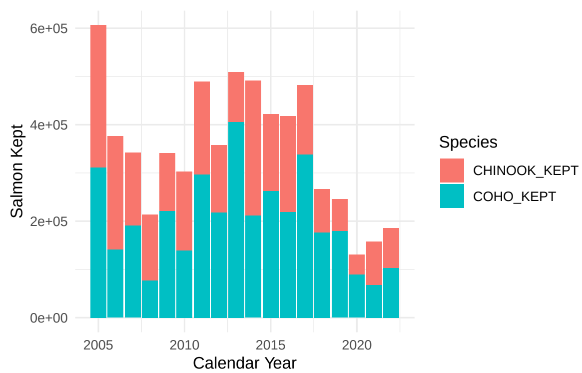


(a) Coho and Chinook

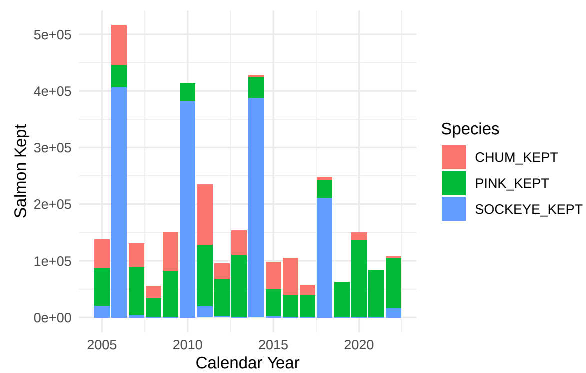


(b) Chum, Pink, and Sockeye

Figure 2: Salmon Catch Data from 2002-2022 (Seine)



(a) Coho and Chinook



(b) Chum, Pink, and Sockeye

Figure 3: Salmon Catch Data from 2002-2022 (Troll)

Figure 1, Figure 2, and Figure 3 show comparitive catch estimates between the different methods of fishing with some years finding more use or success in certain methods over others. With these variations, we aim to analyze if certain methods should be used over others due to their effectiveness, sustainability, or otherwise.

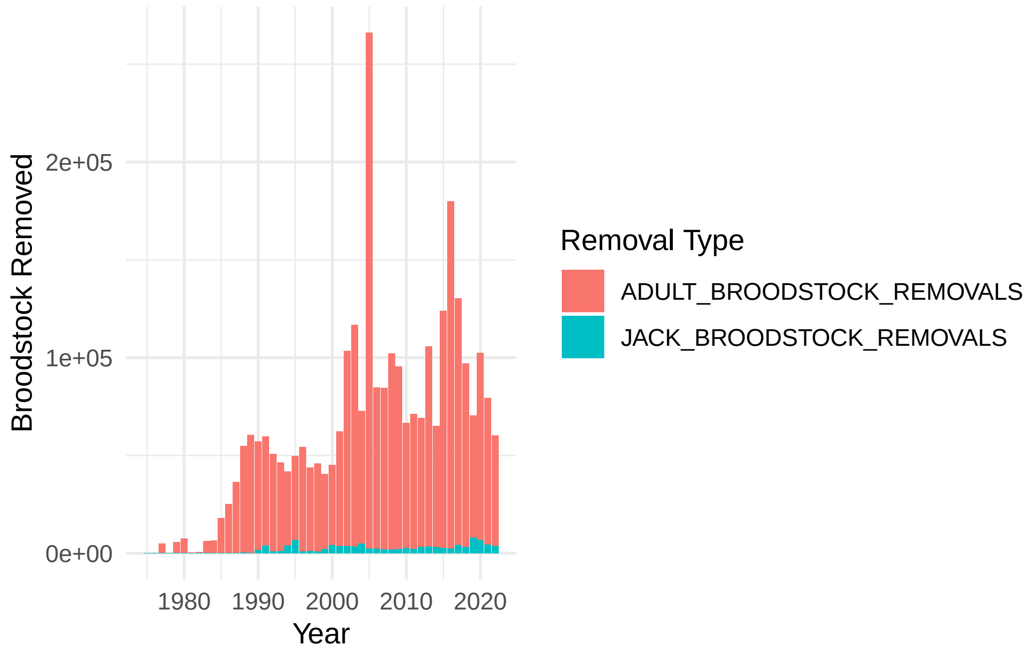


Figure 4: Salmon Broodstock Removals From 1975 - 2022

Figure 4 and Figure 5 show the trends of population in relation to breeding efforts. It is evident that as salmon populations have declined, more effort is being made in trying to repopulate as shown by the increase in broodstock removals in Figure 4. With this, the model will aim to capture the true effectiveness of these efforts.

For the purposes of this report, salmon species were grouped together and total populations irrespective of area were considered instead. The health of salmon populations within species is closely connected, spawning at the same time, maturing roughly at around the same time ("Salmon Life Cycle and Seasonal Fishery Planning" 2024). Due to this reasoning as well as testing with separate species showing similar results it was decided that species would be considered all the same for the purposes of this report.

This data was downloaded, cleaned, parsed, analyzed, and visualized using R (R Core Team 2023), a statistical programming language, with package support from `tidyverse` (Wickham et al. 2019), a collection of libraries which included the following packages that were utilized:

- `ggplot2` (Wickham 2016)
- `dplyr` (Wickham et al. 2023)

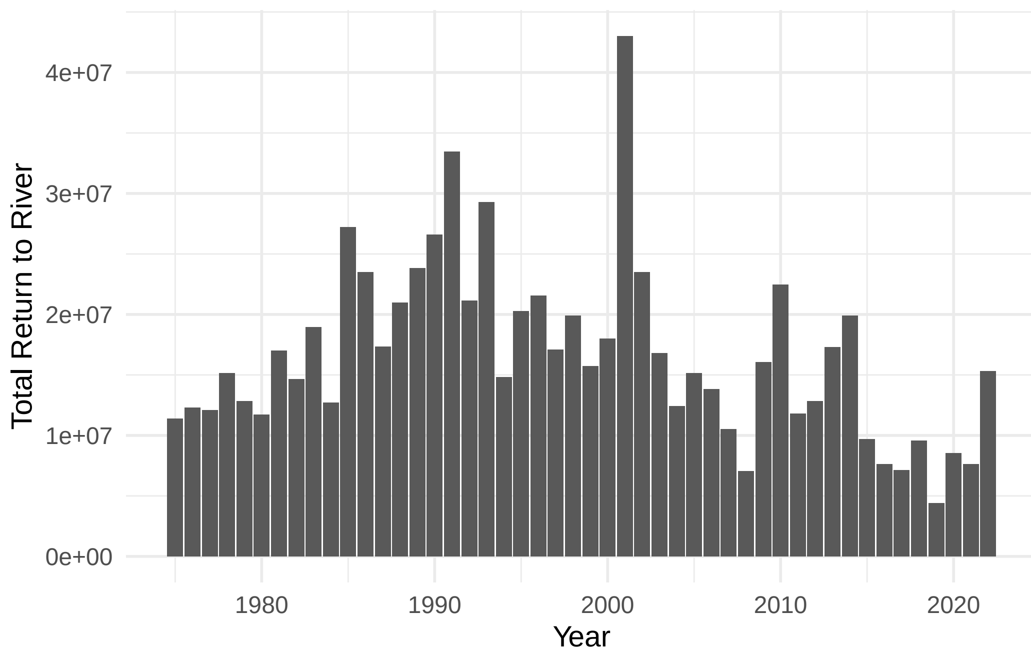


Figure 5: Salmon Populations From 1975 - 2022

- `readr` (Wickham, Hester, and Bryan 2023)
- `tibble` (Müller and Wickham 2023)

For additional assistance with data storage, the `arrow` (Richardson et al. 2024) package was used and for report generation, the `knitr` (Xie 2023) package was used. For testing / verifying data the `testthat` (Wickham 2011) package was used.

3 Model

To create the linear model we made use of the `rstanarm` (Goodrich et al. 2024) package, and to summarize the results we made use of the `modelsummary` (Arel-Bundock 2022) package.

In particular we aim to predict salmon populations based on commercial fishing habits and previous year's spawning health.

3.1 Catch Model

The first model that was created was intended to discover whether the amount of fish harvested through commercial fisheries and the amount of vessels actively harvesting significantly impacted salmon population in Pacific Canada.

We expect that an increase in the amount of fish harvested would impact the population, so we aim to ensure that commercial fishing was and will be done in a controlled and sustainable way. Here we are really testing the effectiveness of fishing regulations and license allocations that the Canadian government has put in place to protect salmon populations.

Therefore the model we are interested in is:

$$
\begin{aligned}
\text{salmon-population}_i | \mu_i, \sigma &\sim \text{Normal}(\mu_i, \sigma) \\
\mu_i &= \beta_0 + \beta_1 \text{vessel-count}_i + \beta_2 \text{boat-days}_i \\
&\quad + \beta_3 \text{salmon-kept}_i + \beta_4 \text{salmon-released}_i \\
&\quad + \beta_5 \text{percentage-gill-net}_i + \beta_6 \text{percentage-seine}_i \\
&\quad + \beta_7 \text{percentage-troll}_i \\
\beta_{0,1,\ldots 7} &\sim \text{Normal}(0, 2.5) \\
\sigma &\sim \text{Exponential}(1)
\end{aligned}
$$

`salmon-population`, `vessel-count`, `boat-days`, `salmon-kept` and `salmon-released` are all as they were in Table 3, Table 4, and Table 5, accounting for the frequency and quantity of harvest.

`percentage-gill-net`, `seine`, and `troll` account for how much of the total amount of salmon harvested came from that respective method, since all salmon species and fishing methods were aggregated as mentioned in the data section.

These variables are included to see if certain methods of fishing have a greater or lesser effect on the salmon population.

Table 6 shows a model summary for this model, this will be discussed further in the results section.

3.2 Yearly Model

The second model uses past year's spawning data to predict the next year's populations. It is reasonable to expect that bad spawning rates one year can affect future year's spawning rates. With NOAA stating that the most common age of returning and spawning adults being 4 years old ("Salmon Life Cycle and Seasonal Fishery Planning" 2024), the predicted variable is the salmon populations observed 4 years in the future.

There are also 2 types of spawning data as shown in Table 2 vs Table 1, being natural vs human cultivated, so the model takes into account those factors, aiming to see the the natural sustainability of salmon populations as well as the impact of protected and selective breeding on those populations.

Therefore the model we are interested in is:

Table 6: Predicting the Salmon Population given commercial fishing catch estimates

	Salmon Population
(Intercept)	12 306.476
	(45 307.956)
VESSEL_COUNT	−4.155
	(2.191)
BOAT_DAYS	0.156
	(0.276)
SALMON_KPT	0.001
	(0.000)
SALMON_RLD	−0.013
	(0.013)
PERCENTAGE_gill_net	104.471
	(461.128)
PERCENTAGE_seine	3.326
	(457.769)
PERCENTAGE_troll	−128.949
	(461.273)
Num.Obs.	18
R2	0.778
R2 Adj.	0.550
Log.Lik.	−163.998
ELPD	−171.7
ELPD s.e.	2.8
LOOIC	343.3
LOOIC s.e.	5.6
WAIC	340.2
RMSE	1843.14

$$
\begin{aligned}
\text{next-year-salmon-population}_i | \mu_i, \sigma &\sim \text{Normal}(\mu_i, \sigma) \\
\mu_i &= \beta_0 + \beta_1 \text{adult-broodstock-removals}_i + \beta_2 \text{jack-broodstock-removals}_i \\
&\quad + \beta_3 \text{total-broodstock-removals}_i + \beta_4 \text{other-removals}_i \\
&\quad + \beta_5 \text{total-return-to-river}_i \\
\beta_{0,1,\ldots 5} &\sim \text{Normal}(0, 2.5) \\
\sigma &\sim \text{Exponential}(1)
\end{aligned}
$$

Where the variables are defined the same way as mentioned when discussing Table 2 and Table 1, with the except to `next-year-salmon-population`, which is the population of salmon 4 years after a certain observation was made as mentioned above.

Table 7 shows a model summary for this model, this will be discussed in the results section.

4 Results

4.1 Catch Model

The model summary from Table 6 shows the relationship between fishing activity and salmon populations. The model suggests that an increase in the amount of commercial vessels fishing for salmon on the water correlates with a decrease in the salmon populations. This is an expected result, with more pressure on fish, the more the population will suffer. Surprisingly however, the number of days spent fishing shows a slightly positive correlation. This unexpected finding suggests that spreading out fishing activity over more days may alleviate pressure on salmon populations, contributing to their preservation.

Then looking to the actual catch numbers, it seems that the actual amount of salmon caught doesn't have a major impact on the salmon populations, which is a good result to have. This means that the restrictive measures placed on commercial fishers are working and are preventing the fishing industry from irreversibly depleting this resource. This suggests that it is not just about the amount of salmon that are actually removed from the ecosystem, but rather how much human interference from the mere act of fishing an ecosystem can handle. Fishing for salmon (and any other fish for that matter) in a destructive way can have impacts on the food chain that affect the salmon the same, even if the catch numbers do not portray that fact.

More interestingly, there is a significant difference between the different methods of fishing to the salmon population. Specifically, Table 6 suggests that when trolling is the dominant fishing method, salmon populations tend to be lower compared to periods when gill nets are prevalent. Seine nets, on the other hand, represent a middle ground, with lesser effects on salmon populations. These findings show the importance of considering the ecological

Table 7: Predicting the Salmon Population in 4 years time given a year's spawn statistics

	Salmon Population
(Intercept)	2343.124
	(465.448)
ADULT_BROODSTOCK_REMOVALS	−0.001
	(0.004)
JACK_BROODSTOCK_REMOVALS	−0.199
	(0.087)
TOTAL_BROODSTOCK_REMOVALS	0.001
	(0.002)
OTHER_REMOVALS	−0.003
	(0.002)
TOTAL_RETURN_TO_RIVER	0.146
	(0.191)
Num.Obs.	30
R2	0.424
R2 Adj.	0.131
Log.Lik.	−235.656
ELPD	−243.2
ELPD s.e.	7.7
LOOIC	486.4
LOOIC s.e.	15.4
WAIC	484.3
RMSE	586.80

implications of different salmon harvesting methods and the need for targeted management strategies to sustainably manage future salmon populations.

4.2 Yearly Model

From the model shown in summary by Table 7, the removal of salmon for broodstock only shows a slightly negative or possibly neutral relationship with future salmon population. The human influence through breeding and stocking salmon does not seem to have a greatly positive or negative effect on the overall population, but it suggests that other factors are at play. As mentioned in the data section and shown in Figure 4 Figure 5, it seems that while broodstock removals increase, population decreases, and since this model doesn't suggest a strong correlation between them, they must be connected in some other way. It is reasonable to say that this actually suggests that increased broodstock removals are a response to declining population, and are aimed at restoring losses that were occurred another way. While increased breeding doesn't increase the population over what it was before, it maintains it, appearing as a neutral relationship in a linear model. To be truly sure, research into the breeding and stocking process must be done to verify these results.

Looking at the return to river variable in Table 7, this suggests that most of the increase in population is closely related to how succesfully and plentiful the spawning was 4 years ago. The smolt (baby salmon), that hatched 4 years ago, most likely become the salmon that appear in the waterways to spawn now after they have reached maturity. This shows how important future planning is in salmon conservation, as impacts on population may not be seen immediately. Preventative measures are necessary, as reactive measures to suddenly declining salmon populations will not take effect for a significant period of time.

5 Discussion

5.1 Weaknesses

The datasets that were used provided location data in the forms of management regions which were not made use of in this dataset. Especially for the spawning regions, other factors could be taken into account to get a better understanding on what hardships a region is facing, and what fishing regions have greater impact to those spawning regions. This paper dealt with the general impacts and changes of Pacific Canadian salmon, but working at a smaller scale may help with identifying regional differences and allow different approaches depending on such.

In addition, enviornmental factors were not considered in this report, although they were suggested to have correlation, due gaps in explanation for change just from human intervention. Disease, climate, food chain fluctuations, can all have impacts on the health and abundance of the salmon population, factors that can be changed in other ways and through different regulations.

As for the data itself, there were a lot of missing values, which may impact the accuracy of the results, with some waterbodies / watersheds potentially being underrepresented when calculating population. Similarly, both the salmon population and catch data are both estimates made by Fisheries and Oceans Canada, meaning that the counts are not 100% accurate. If these estimates were made erroneously, this may also impact the accuracy of the models and results.

5.2 What was done and should be done

Through the use of linear models, we were able to make inferences on the world, in this case the world of salmon fisheries, results that could have impacts for both recreational anglers and the commercial fishing industry. By analyzing past fishing trends and spawning statistics, we were able to verify our expecations about human driven impacts on salmon populations. We saw the successes and failings of restrictive fishing regulations as well as how salmon breeding and stocking has supported the salmon population during a period of decline.

From this analysis of salmon's decline, we aim to reiterate the importance of mitigation strategies and management plans to restore salmon populations and promote sustainable fishing practices. Governing bodies should focus on what has been working and put further emphasis in places which have been failing. Preserving healthy salmon populations is not only vital for biodiversity and ecosystem balance but also for meeting the demands of the fishing industry. Despite the significant correlations found between fishing frequency, previous salmon populations, and artificial breeding practices, it is clear that other factors not captured in the available data may also contribute to salmon population fluctuations. Further investigation into these factors should be done to gain a more comprehensive understanding of the dynamics affecting salmon populations and to inform effective conservation efforts moving forward.

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