Population Modeling and Economic Valuation of a Coho Salmon (*Oncorhynchus kisutch)* Population in the Scott River Basin

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Environmental Science and Policy Capstone

Land Acknowledgement

The authors of this paper would like to acknowledge that the research performed in this project is analyzing a location that is within the ancestral land of Confederated Tribes of Siletz Indians, Confederated Tribes of Grand Ronde, Cow Creek Umpqua, Karuk, Modoc, Tolowa Dee-ni', and Takelma tribes. Additionally, this project's research is centrally focused around salmon, which is a deeply culturally significant species to these tribes. This project intends to quantify the economic value of salmon. The authors would like to acknowledge that this is a Western technique and that there is no economic way to quantify the cultural significance of the salmon to native tribes. Furthermore, in an attempt to disrupt the erasure of native tribes due to colonialism, this project will utilize an economic evaluation from a Western perspective, but will continue to advocate for more traditional means of salmon valuation and management.

Abstract

Coho salmon (*Oncorhynchus kisutch*) are a significant species of concern within the Scott River Basin and the larger Klamath River system of Northern California. Coho play important cultural, economic, and ecosystem roles and this subspecies is listed as threatened under both the State and Federal ESA. Increasing water usage by agriculture and extended periods of drought have reduced both the habitat availability and quality for coho to spawn. The commercial agricultural industry is a dominant employer in the region and the largest water user. The main goal of this study is to determine the economic benefit of coho salmon in the Scott River. This is done through three primary steps; statistical analysis of water discharge and salmon migration, population modeling to predict future salmon populations under set water flows, and a cost-benefit analysis. The value of these fish was calculated to be a per market value of $2,774 per smolt. This can be used by conservation management entities to inform policy making within the region with concerns to ESA management and future development of water policy.

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I. Introduction

The Scott River Basin is located in Siskiyou County, California and is a sub-basin of the larger lower Klamath River Basin. Connecting many parts of the landscape in Northwest California, the basin is 512,320 acres and is predominantly privately owned at 63%, with the remaining 37% owned by the federal government (Charnley, 2018). The Basin is surrounded by several mountain ranges, including the Marble and Salmon Mountains and the Trinity Alps, the 60 mile Scott River starts its headwaters in these mountains before winding down into the Klamath River (Siskiyou, 2008). The climate in this region is montane mediterranean, with extremely hot dry summers and cool wet winters (USDA, 1997). The lower elevations are dominated by chaparral and grassland, while the rugged mountains are covered in Douglas-fir and a variety of pine species (USDA, 1997). Historically, the highest stream flows in the watershed occur during fall rains (November) and seasonal mountain snow melt (April and May) (Siskiyou County, 2008). Low flow months include August and September, where historically flows were as low as 50 cfs (Van Kirk, 2008). Since monitoring for drought began in 2000, the average low flow for the Scott River has declined significantly (Van Kirk, 2008).

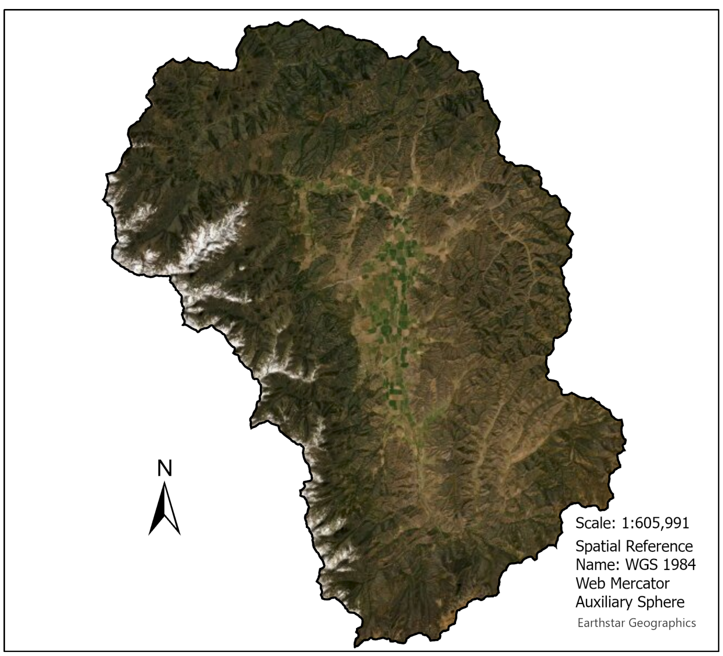

Figure 1. Aerial basin map of the Scott River in Northern California.

This river system first experienced significant diversions back in the 1800s. Historically logging and mining were active industries within the basin. As these resources were extracted and exploited, agriculture took a stronghold. Currently, agriculture is one of the largest water users within the basin, over 138,000 acres of cropland are known to be irrigated (Siskiyou County, 2019). Agriculture is the dominant industry within this county, using over 750,000 acres and accounting for an average of 350 million in exports annually between 2015-2019 (Siskiyou County, 2019). Agriculture is the 5th largest employment sector in the county with over 1,000 documented employees (Miller, 2016). Etna, CA (2020 population of 678) and Fort Jones, CA (2020 population of 695) are the largest towns in the watershed, both located in Siskiyou County, California (USCB, 2021). The poverty rate in Siskiyou County ranked at just over 17% in the 2020 U.S. Census (U.S. Census Bureau, 2021). It is important to note that with such a high rate of poverty, activities or regulations that restrict economic activity are viewed negatively by a vast majority of the population.

While agriculture is the dominant industry in the region, commercial and recreational fishing bring in additional revenue. The economic contributions of commercial and recreational fishing are more significant in the lower Klamath Basin as a system and further downstream near the California coast. During the 2019 season, landings in the north coast salmon fishery totaled 1.19 million USD (CDFW, 2019). This fishery has experienced a significant decline since 1996 as populations for salmon have reduced (NMFS, 2021). Indigenous peoples hold deep cultural values of Coho salmon in this region, including but not limited to, the Confederated Tribes of the Siletz Indians, the Modoc, Karuk, and Shasta. Salmon trolling is considered a major fishery on the North Coast and in 2020 14.4 million USD in Chinook and Coho landings took place (PFMC, 2021). Commercial harvest from the Yurok and Hoopa Valley tribal harvest allocation is allowed in years where there is a harvest surplus, accounting for an additional one million USD in landings (PFMC, 2021).

Native fish of concern within the Basin include the threatened Coho salmon (*Oncorhynchus kisutch*), threatened Chinook salmon (*Oncorhynchus tshawytscha*), and Steelhead (*Oncorhynchus mykiss*) (Moyle, 2002). The Coho salmon in the Scott River are one of the last self-sustained runs in California, meaning that hatchery fish have not yet infiltrated the genetic pool or supported the run of wild salmon (Moyle, 2002). Coho salmon are anadromous and spend most their life out at sea before returning to their birthriver to spawn and die. In this region they are listed as threatened on both federal and state levels (Moyle, 2002). These fish are deeply important to local tribes and the broader ecosystem. Chinook and steelhead populations are also of concern in the area (Moyle, 2002). Home to many species of Native fish, including threatened fish, the Scott River provides a key area of study when examining the environmental impacts on these species.

Determining the economic value of an imperiled species is a useful tool in planning conservation management strategies. Other studies conducted on the economic valuations of fisheries have taken place across the Pacific Northwest. The vast amount of existing economic valuations for Coho Salmon have been derived from litigation following fish kills correlated to dams, hazardous waste, and water way blockage. The Columbia River, Coho salmon fishery has been estimated in high detail (Morton, 2017) as it is facing increasing threats to decline, many of which have already been felt on smaller rivers further south. The Rogue River Coho salmon fishery is of a smaller scale and more similar to the Klamath and smaller Scott River fisheries (Helvoigt, 2009). This project will be different from the previously stated studies because it will be focusing on an area that has not had a recent major fish kill that is correlated to a catastrophic event.

The main goal of this project is to determine the economic value of salmon in the Scott River Basin. Currently the economic value of native coho in the Scott River Basin has not been quantified. Quantifying this value is crucial in developing a better understanding of the economic relationship of native fish in regards to water allocation utilizing the public trust doctrine. To achieve this, the use of regression analyses, population modeling, and market based economic valuation methods will be utilized. Specifically, the project research will look at the relationships of native fish and ecological economics, and the overall economic value of salmon in the Basin. Once the economic valuation has been completed, its results will then be used to create public policy recommendations.

II. Methods

Variables of interest include Scott River average discharge (ft^3/s), Scott River average salmon escapement counts, Pacific Coast regional salmon counts from commercial harvests, and the Pacific Coast regional net revenue of salmon. Salmon escapement count refers to the number of spawning salmon that have gone out to sea and returned to their birth river to spawn. Akin to larger fisheries management strategies, this run is measured and managed based on escapement goals. These goals drive the determination of regulations for commercial and sport harvest. The salmon counts from commercial harvests within the Pacific Coast region are determined based on landings which is the number of fish caught and sold within the United States. Finally, the regional net revenue of the salmon is determined by subtracting the costs of production from the revenue of the good, resulting in the revenue gained.

Statistical Analysis

A regression analysis (R1) was performed in R to address the possible relationships between average discharge and average salmon escapement of the same year. This analysis aims at understanding the influence of the water quantity in the river on salmon spawners. Using independent variable discharge values and dependent variable salmon escapement values, the following null hypothesis was formed; changes in discharge (ft3/s) will have no effect on salmon escapement in the Scott River for the same year. Thus the alternative hypothesis is as follows, changes in discharge (ft3/s) will have an effect on salmon escapement in the Scott River for the same year. It was predicted that increases in discharge (ft3/s) would have a positive effect on salmon escapements in the Scott River because increased water quantity provides increased habitat and decreased water quantity reduces habitat for salmon to spawn.

A second regression analysis (R2) was performed in R to address the possible relationships between average water discharge and average salmon escapement with a lag of 3-4 years. This analysis aims at understanding the influence of the water quantity in the river on salmon juveniles. Using the independent variable discharge and the dependent variable salmon escapements the following null hypothesis was formed. Changes in discharge (ft3/s) will not have a relationship with salmon three years later. Thus the alternative hypothesis is as follows, changes in discharge (ft3/s) will have a relationship with escapement three years later. It was predicted that increases in water discharge (ft3/s) will have a positive effect on salmon escapements in the Scott River because increased water quantity provides habitat and decreased water quantity reduces habitat for salmon juveniles to survive.

The third analysis (R3) used a statistical regression in R to determine possible relationships between daily water discharge (ft3/s) and upstream migration of spawning coho salmon. Data for this was sourced from the California Department of Fish and Wildlife's fish weir and the USGS water gauge downstream of the weir. Using independent variable discharge values and dependent variable salmon escapement values, the following null hypothesis was formed; changes in discharge (ft3/s) will have no effect on salmon escapement in the Scott River for the same day. Thus the alternative hypothesis is as follows, changes in discharge (ft3/s) will have an effect on salmon escapement in the Scott River for the same day.

The fourth analysis (R4) used the same approach as the third, but using logarithmic transformation values of discharge. It was hypothesized that the water discharge dataset is not normally distributed, so the utilization of logarithmic values accounts for potential unequal distribution of variance. This regression analysis used the same hypotheses as the R3 analysis in R.

Population Model

A population model was built to predict the future population of coho under varying discharge levels. A dynamic Coho salmon population conceptual model was developed in Insight Maker to outline the possible structure for the complete simulation model (Figure 2).

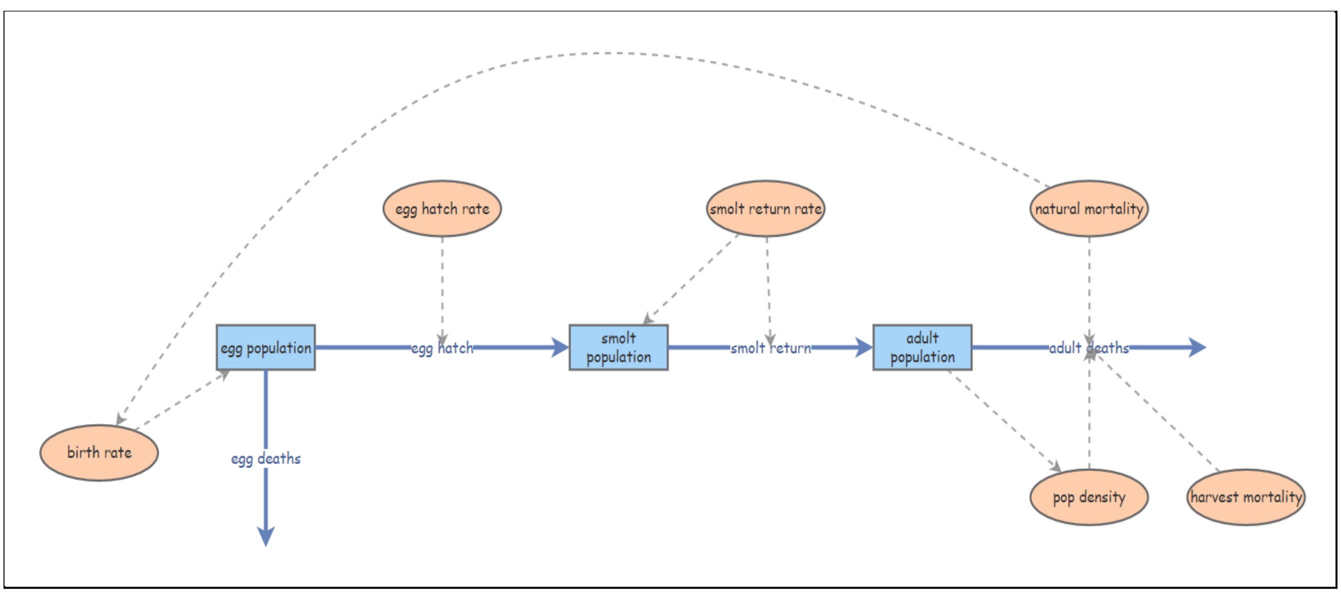

Figure 2. Conceptual model of coho salmon population dynamics created in Insight Maker.

The conceptual model shows three main state variables, or stocks. They are egg population, smolt population, and adult population. With the aim to simplify the model, only three life stages are included by using averages of survival rates from the life stages between the egg and smolt stages. The smolt population stock is set as a conveyor to better represent the spectrum of ages within the population. Notable flows include, egg deaths, egg hatch, smolt return, and adult deaths. The smolt population stock does not include its own outflow of deaths because the natural mortality for this life stage is accounted for within the smolt return rate variable. Key variables for the overall salmon life cycle include birth rate, egg hatch rate, smolt return rate, population density, harvest mortality, and natural mortality.

The dynamic simulation model was created in STELLA to better understand the structure of the ecological system and the relationships between the variables and future trends in the population. In the final simulation model (Appendix Figure 1A), changes were made to the overall structure and different variables were included to better account for the life cycle of a coho salmon. The conceptual model was overly simplified, therefore the simulation model now includes state variables, eggs, fry population, smolt population, coho in ocean, and spawning adults. The differential equations for the STELLA simulation model are shown in Table 1. Each of the state variables, excluding coho in ocean, are set as conveyors. The eggs stock is set to a transit time of four months to include time for the alevin stage that is not represented in the model as a stock. The fry stock has a transit time of six months and finally the spawning adults have a transit time of one month due to their imminent demise following spawning. The coho in ocean stock is a bucket and will account for the smolts staying in the ocean for two years with the help of a monthly counter variable. The state variables all include outflows to account for deaths at each life stage and inflows leading to the next stage. Important variables include population density (calculated specifically for the Scott River), eggs per female, egg hatch rate, smolt return rate, and finally, ocean mortality. Table 2 in the Appendix displays each variable in the model as well as their type, value, and reference or calculation. Additionally, it displays the variables representing the relationship of discharge and migration and those used to drive the economic valuation.

Table 1. Simulation model differential equations table

Differential Equations	
State Variable Name	*Equation Format*
Eggs	*dP/dT= eggs laid-to fry-nonviable eggs*
Fry population	*dP/dT= to fry-to smolt-fry deaths*
Smolt population	*dP/dT= to smolt-to ocean-deaths*
Coho in ocean	*dP/dT= to ocean-to scott- deaths*
Spawning adults	*dP/dT= to scott- adult spawning*

The model runs in a monthly time step and simulates the next 20 years to demonstrate the average lifespan (three to four years) of five generations of Coho salmon (NOAA, 2021). The simulation model has been calibrated to the Scott River by using population data from the 2020 Scott River Salmon Studies Final Report. Overall, the population model is a tool to examine the ecological dynamics of the study area which can then be used to inform the economic valuation. Specifically looking at coho salmon population changes driven by environmental changes within the Scott River, the model aims at creating a better understanding of these relationships. The model created in this project is limited by the data available on coho migration and population, by the averages used to simplify the model, and by limited data for environmental variables. The model occurs in a monthly time step to better mirror the movement through the life stages.

Economic Valuation

The first step in the benefit cost analysis is identifying key goods and services that the Scott River provides and determining whether or not they are a market good. In an article by Rudolf Groot et. al, the authors adapt a classification and description for ecosystem functions from Costanza et al., 1997. Using these classifications, seven ecosystem functions were identified for the Scott River ecosystem and are listed in Table 2 (viewable in the appendix). These functions demonstrate values that were not included in the economic quantification for coho in this project. While primarily non-market values, they must still be given consideration when looking at the complexity of this system and the benefits coho provides. With ecosystem functions, goods, and services identified, it provides context for the action of the benefit cost analysis. The action for the benefit cost analysis is to allocate water to salmon during drought conditions. Table 2 demonstrates the qualitative benefits and costs of either performing or not performing this action.

To calculate the economic value of Scott River coho, an average of Scott River smolts were taken from the smolt brood years of 2005 to 2019 (Knechtle et al. 2021). Rounding the survival rate of smolts making it to the ocean to 80% (Pisano, 2012), the surviving smolts are then multiplied by the average weight of a coho to result in the average pounds of coho coming out of the Scott. Taking the current (2022) average price per pound and multiplying it by the average pounds of coho from the Scott, the economic contribution of Scott River coho is then derived.

To calculate the economic value of commercial agriculture operations within the Scott River Valley, we used existing data from the Siskiyou Department of Agriculture 2019 Annual Crop Report. Table 4 is from this county data with one column added to determine the net revenue (Siskiyou County, 2019).

The costs of salmon fisheries in the region are then calculated by utilizing the National Marine Fisheries Service Estimated California Commercial Salmon Operation Costs (Hackett and Hansen, 2008). These calculations are derived from 27 fixed and variable cost categories that represent all costs associated with the operation of a vessel in California. These costs are then multiplied by the vessels operating in the industry to calculate the total industry cost. The amount of vessels is calculated by multiplying the county share of the industry by the total vessels. The number of vessels is then multiplied by total cost.

The benefits of Coho were calculated by doing a market analysis of the commercial consumptive use value of salmon. The quantity of salmon from commercial harvests in the Pacific coastal region, Pacific coast regional market prices, and Pacific coast regional commercial production costs, and the overall net revenue of salmon in the region was determined. Then a discount rate was determined based on a time preference that is reflective of the values placed on salmon today and into the future. This valuation utilized both a 1% and a 3% discount rate.

These net revenues were then programmed into the bioeconomic model in STELLA so the population estimates driven by the model would be calculated. This resulted in calculating the economic benefit under 8 different scenarios, under both baseline and low-flow conditions, at both the 1% and 3% discount rate, and with per pound wholesale values of $2.15 and $3.43. The eight scenarios all resulted in different economic values.

III. Results & Discussion

Statistical Analysis

The first analysis, addressing the possible relationships between average discharge and average salmon escapement of the same year (R1), resulted in a potential marginally significant relationship. The alpha level selected was 0.05 and the p-value from the analysis was 0.060, which is slightly greater than the alpha. The results of this analysis were graphed as a scatter plot as seen in Figure 2. Due to the marginal significance, the result cannot be verified through this analysis alone and requires further research. The multiple R squared value of 0.1088 does not explain the model variability in the dependent variable.

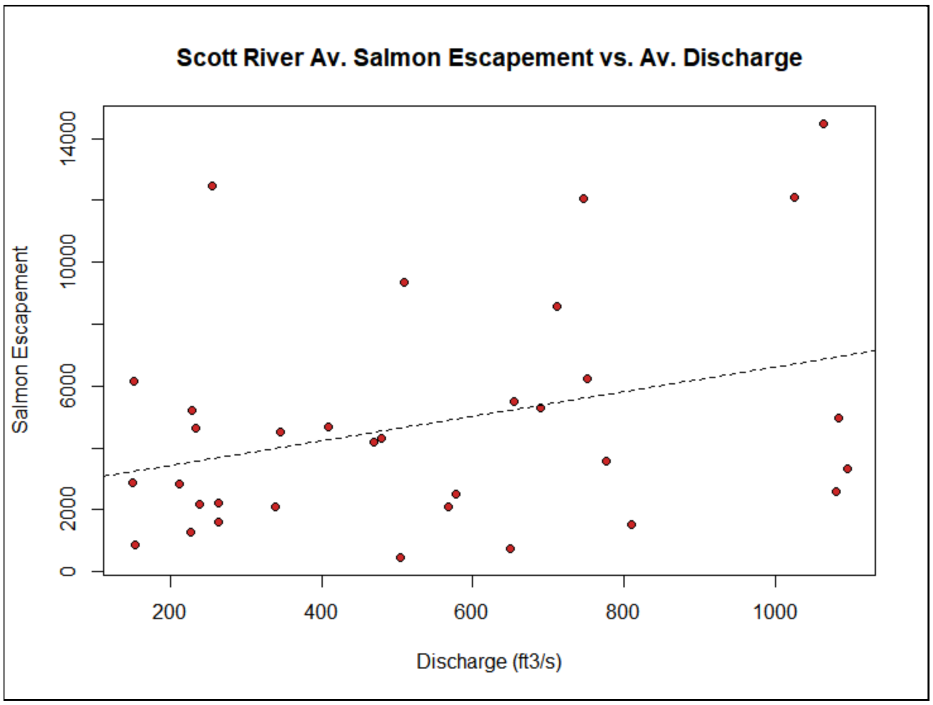

Figure 3. Scatter plot of average salmon escapement and average discharge in Scott River from 1988-2020. Plot demonstrates no strong trends or relationships between variables, except a potential marginal significance depicted with a dashed line.

The second analysis, addressing the possible relationships between average water discharge and average salmon escapement with a lag of 3-4 years (R2), resulted in a significant relationship. The alpha level selected was 0.05 and the p-value from the analysis was .7543, which is greater than alpha. The results of this analysis were graphed as a scatter plot as seen in Figure 3. The result of the second analysis of escapement with discharge in a lag year resulted in a non-significant relationship. The multiple R squared value of .0032 does not explain the model variability in the dependent variable. Overall, both analyses did not support strong relationships between the variables. Both alternative hypotheses are rejected and both null hypotheses are accepted, there are no strong relationships between the discharge and escapement both in the same year and three years after.

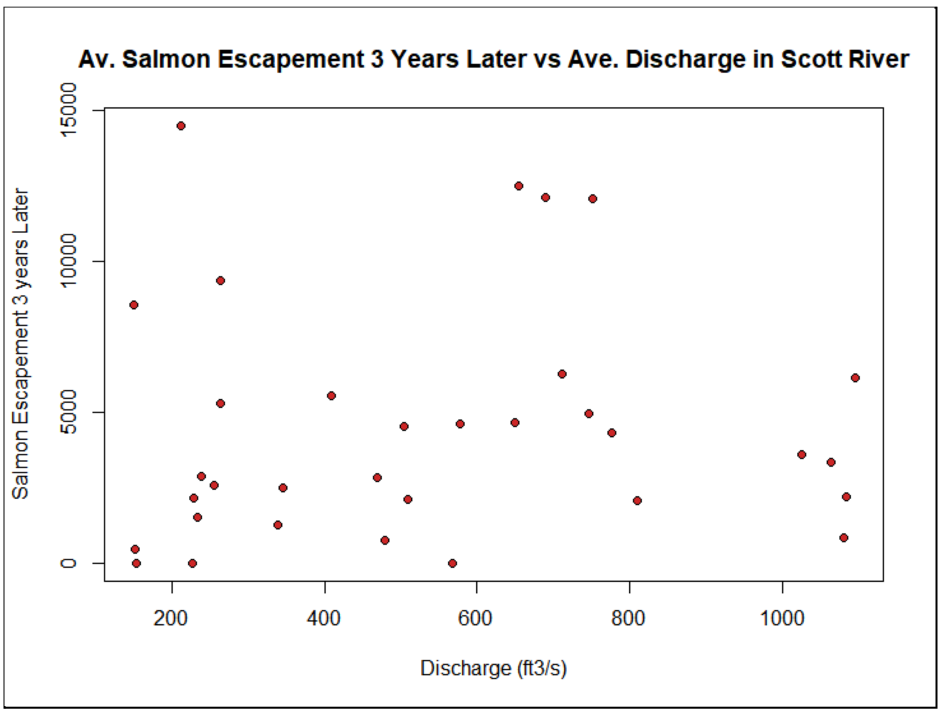

Figure 4. Scatter Plot of average salmon escapement and average discharge in Scott River with 3 year lag. Plot demonstrates no significant trends or relationships between variables.

The R1 and R2 models used an annual timescale, given the results of these regressions and existing peer-reviewed models we determined it was not appropriate to only use an annual timescale to assess potential correlation. We then gained access to data that broke down coho migration into daily counts and used this to conduct R3 and R4. These regressions provided a more appropriate time scale for this analysis.

Seen in figure 5 below, the R3 model demonstrated a significant linear relationship (the alpha level selected was 0.05 while the p-value was 0.04215) between daily salmon escapement and the average daily discharge in the Scott River. Upon further analysis, this relationship was shown to be not normally distributed through the use of a histogram plot (Figure 6). Due to the data not being normally distributed, the R4 analysis was completed to better meet the assumptions of the regression test.

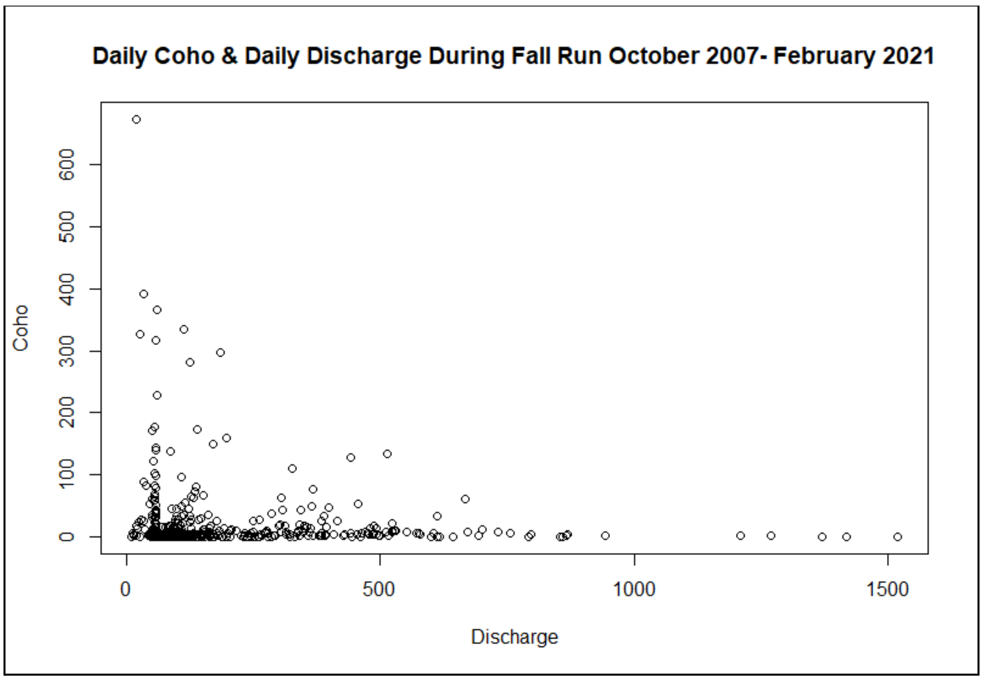

Figure 5. Scatter Plot of daily salmon escapement and average daily discharge in Scott River. Plot demonstrates no significant relationship between discharge and migration.

The R4 model is shown in Figure 6 below. This analysis demonstrated no significant linear relationship (the alpha level selected was 0.05 while the p-value was 0.0921) between the daily escapement and the logarithmic 10 value of daily discharge in the Scott River. The plot of this curve shows an inverted 'U' with a clear lower threshold.

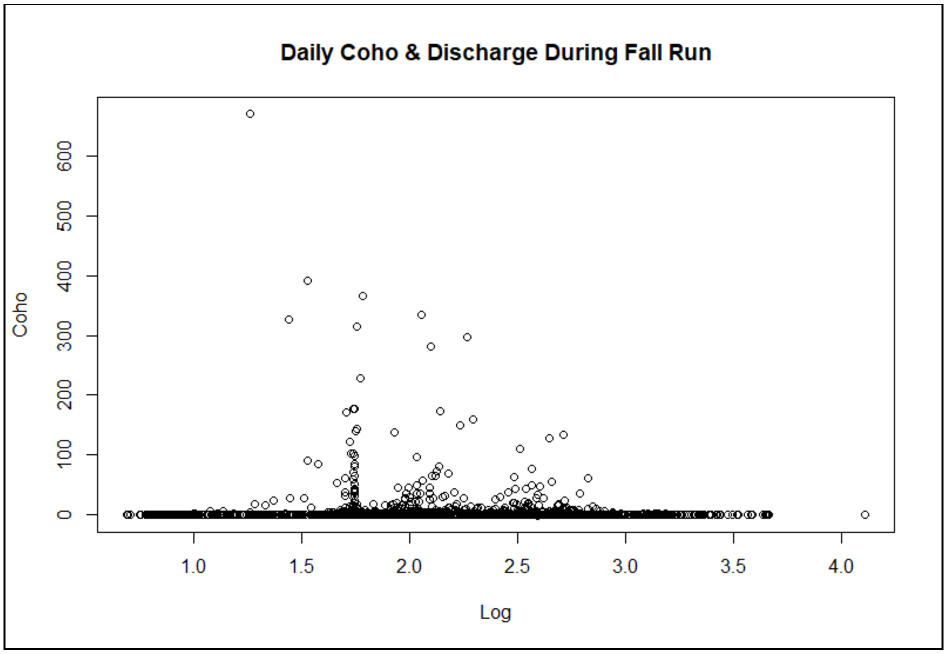

Figure 6. Scatter Plot of daily salmon escapement and logarithmic value of average daily discharge in the Scott River. Plot demonstrates no significant relationship between discharge and migration.

Population Model

The population model was utilized to run several scenarios of varying discharge and management options. The model is capable of running the maximum number of coho through the river at any given time regardless of water availability. However, the following results all apply the same constraint, that water in the river constrains the maximum fish potential. The first scenario run, total spawning adults, tested the models functionality and accuracy. The population model maintained an equilibrium for the total number of spawning adults in the Scott River over 20 years, see Figure 7. The population figures are driven based on the timing of the life cycle for coho, as such there are eight months where numbers dip to zero due to those months being outside of the spawning season. As seen in Figure 7, the first two cycles of the total spawning adults do not go above 2,500 on the axis. This is due to the fact that the model begins in January, when the previous fall run is coming to a close. The following cycles however, are representing the full four month runs and therefore demonstrate the population hovering just above 2,000 spawning adults. These cycles maintain an equilibrium, or steady pace, through the twenty year simulation. This equilibrium indicates that the model is functioning as intended. Additionally, the results from this model run fall within the recent historical range of the population for coho in the Scott River. This results in a model that is both functional and calibrated to the Scott River.

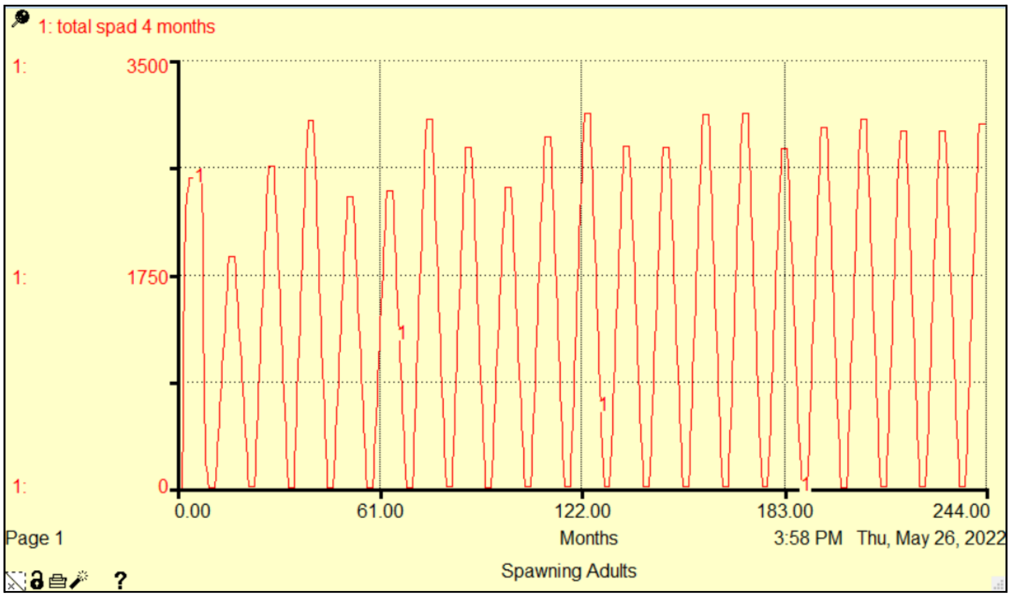

Figure 7. Spawning adult populations at equilibrium.

The second scenario performed was to view the timing of the coho run in relation to water availability. Figure 8 shows the maximum population potential under baseline conditions in the red line. The blue line represents coho migrating to the Scott in the model run. Under baseline settings without restriction to flow, the maximum population potential is just under 1500, with most fish migrating in at the very start of the season.

The third scenario performed also examined the timing of the coho run in relation to water availability. Figure 9 shows the same variables, maximum population potential and coho migrating to the scott in the model run. However in this scenario, they are under constrained flows. The maximum population potential is thus reduced to below 500 and the migration is delayed until further in the season.

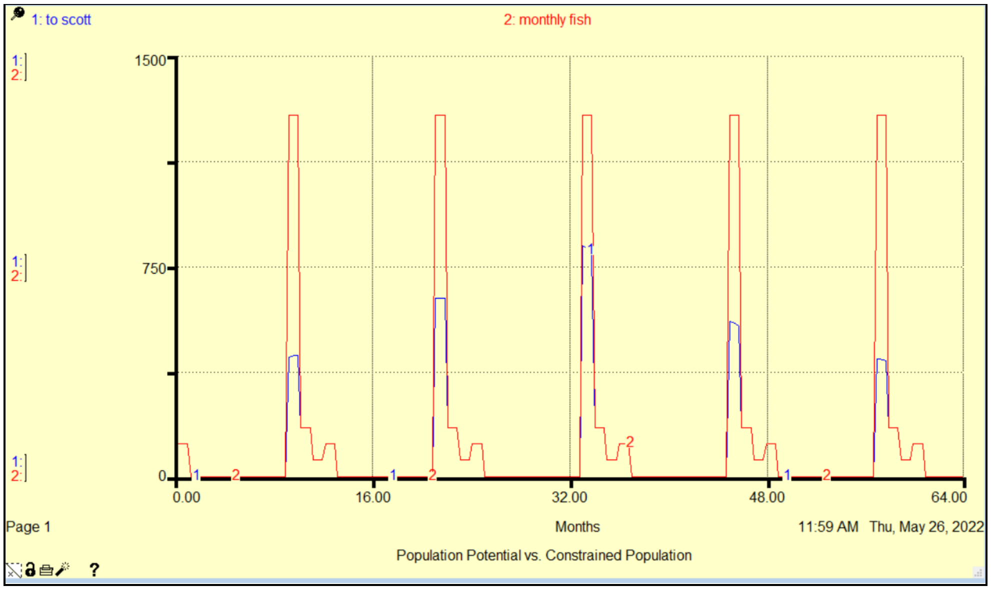

Figure 8. Population model with baseline water flow.

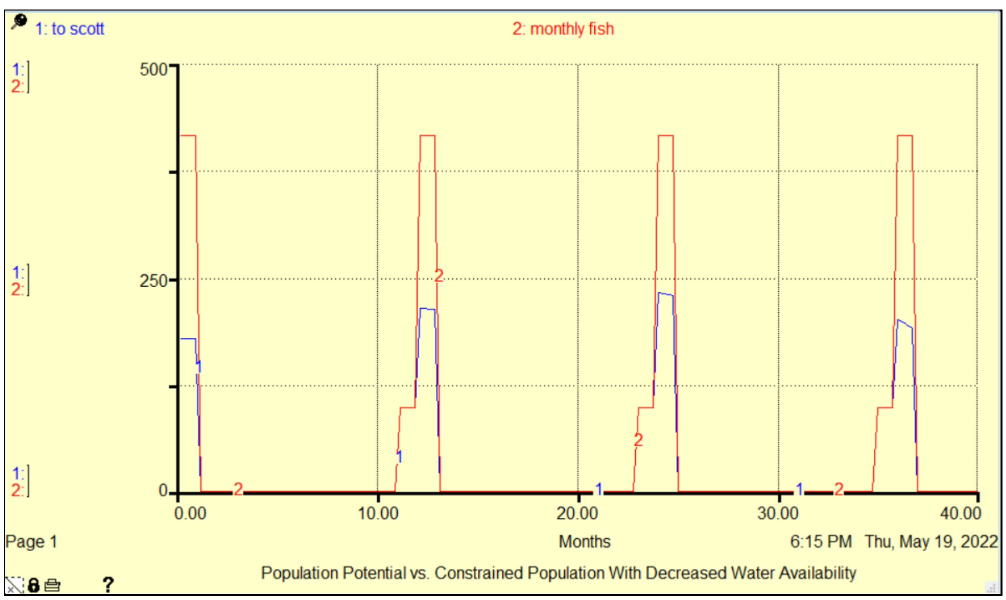

Figure 9. Spawning populations under constrained flow.

Economic Valuation

The economic valuation of coho was performed under baseline and further water constrained scenarios. Baseline utilized the optimal flow value, whereas water constrained was run with restricted flow settings. Each of those scenarios was then run under two different discount rates, 1% which is reflective of an environmental stance and 3% which is reflective of a more traditional discount rate in mainstream economics. Finally, two different price points were utilized due to the variation in the year to year market prices. The first price is representative of the current day (2022) price at $2.15 and the second is a price that has been increased by $1.28 per pound. Below table 4 demonstrates these 8 scenarios.

Utilizing the data derived from the calculations of in the population model for smolts and adults, the calculated baseline economic value of the Scott River coho is just above $6 million spread over the course of 20 years. With constrained water availability, the population plummets, therefore decreasing the potential economic benefit to just over $3 million over the course of 20 years. In a market with a more expensive price per pound, these values increase to $8 million and $4.8 million respectively.

Table 4. Economic Contribution of Scott Coho

	Average Scott Smolts	Average Adult Population	**Economic Contribution of Scott Coho at $2.15 per pound ($ Mil)**	**Economic Contribution of Scott Coho at $3.43 per pound ($ Mil)**
Baseline[a]	22,193	2,982 annual	**$6.3**	**$8.0**
Water Constrained[a]	4,961	574 annual	**$3.0**	**$4.8**
Baseline[b]	22,193	2,982 annual	**$5.2**	**$8.3**
Water Constrained[b]	4,961	574 annual	**$2.6**	**$4.2**

A: 1% Discount Rate
B: 3% Discount Rate

The Siskiyou Department of Agriculture 2019 Annual Crop Report (Table 5), displays the results of their calculations for the economic contribution of agriculture in the Basin. This report looked at Alfalfa, Barley, Wheat, Pasture, and another category labed Other Hay. Each grouping of crops has land per acre and the applied water per acre foot of acre. The price per ton is then multiplied by the yield to get the overall gross revenue. However, the authors of the report did not factor in the costs and only presented the gross revenue. Therefore, a column is added to subtract labor, supply, and land costs to calculate the net revenue of each crop. When looking at these values, the contribution of coho (under baseline conditions) would provide an annual economic benefit that outnumbers the current annual benefits of $150,000 from wheat, barley, and hay mix combined, not including pasture and alfalfa. However, the total combination of all crops still outweighs the economic benefits of coho.

Table 5. Scott River Valley Base Conditions. Author Calculation using data listed in Table 3.

Crop	*Land (ac)*	*Applied Water (AF/ac)*	*Price ($/ton)*	*Yield (ton/acre)*	*Labor Cost ($/ac)*	*Supply Cost ($/ac)*	*Land Cost ($/ac)*	*Gross revenue ($ Mil)*	***Net Revenue ($ Mil)***
Alfalfa	*12, 267*	*1.97*	*193*	*6.4*	*187*	*437*	*482*	*15.25*	***1.68***
Barley	*1,415*	*1.08*	*284*	*2.3*	*122*	*285*	*204*	*0.92*	***0.05***
Other Hay	*546*	*1.97*	*260*	*4.5*	*187*	*437*	*482*	*0.64*	***0.04***
Pasture	*13,948*	*2.3*	*200*	*3.5*	*109*	*254*	*255*	*9.76*	***1.14***
Wheat	*1, 883*	*1.08*	*203*	*3.2*	*122*	*385*	*204*	*1.21*	***0.06***

IV. Conclusion

Understanding the economic value of salmon provides another metric for understanding their ecosystems in conjunction with the local and regional economy. Integrating these fields of study results in new varied holistic approaches to environmental management and environmental policy. It is perceived that these approaches will be further effective than current practices, because the values derived in this analysis can now be used in Western valuation. Previously, the coho maintained a "zero value" in the economic discussion, however now they have a number attached to their overall value. The determined economic benefit of coho under constrained water flows is important to consider in conjunction with current drought conditions and future drought predictions. These determinations will be useful to conservation management groups and entities involved with the recovery of coho populations in the region.

Limitations of this study include utilizing a limited dataset for coho populations, limited data for environmental variables within the population model, and a lack of recorded water usage. The dataset used for examining the relationship between coho and discharge is only for a span of 15 years, during which over half were considered to be periods of extreme drought. The environmental variables used with the population model were based upon a series of historical studies and studies conducted in adjacent water systems. The lack of recorded water usage and quantified water rights severely limit an analysis of the economic value of water and impair the ability to determine where water could be conserved to generate the most meaningful impact. Further studies could be performed to determine the relationship between water discharge and water temperature, and their combined effects on coho. This could help to understand specific impacts and mitigation needs for coho under increasing temperature conditions.

While the work in this paper is an attempt to quantify the economic value of Scott River coho salmon; this quantitative approach cannot substitute for the immense cultural value of this species. Indigenous groups in this region have subsisted off this species for millenia and hold sacred value to it, values that cannot be fully quantified in Western Science. Due to the non-market values of these species and declines in water availability that threaten the overall long term productivity of the coho, water should be allocated to serve in-stream ecosystem functions and goods, despite the economic value of the coho. In addition to the economic values derived, other values should be included when managing water. Traditional means of salmon valuation and management should be equitably considered when making decisions regarding management of coho in the region. Using the economic value of coho as an additional metric, instead of the sole measurement of value, creates an interdisciplinary approach. This will allow for western and non-western techniques to come together and create more appropriate means of valuation.

V. Acknowledgements

The authors would like to take this opportunity to express our deepest gratitude for Dr. John Gutrich for all the generous support, time, and encouragement he has provided from the inception of this project to its very end. The countless hours he spent answering questions and guiding us through the complexities of modeling were an immense help.

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Lastly, we would like to recognize our families and the Southern Oregon University Environmental Science and Policy Department for all their support throughout this project.

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II. Appendix

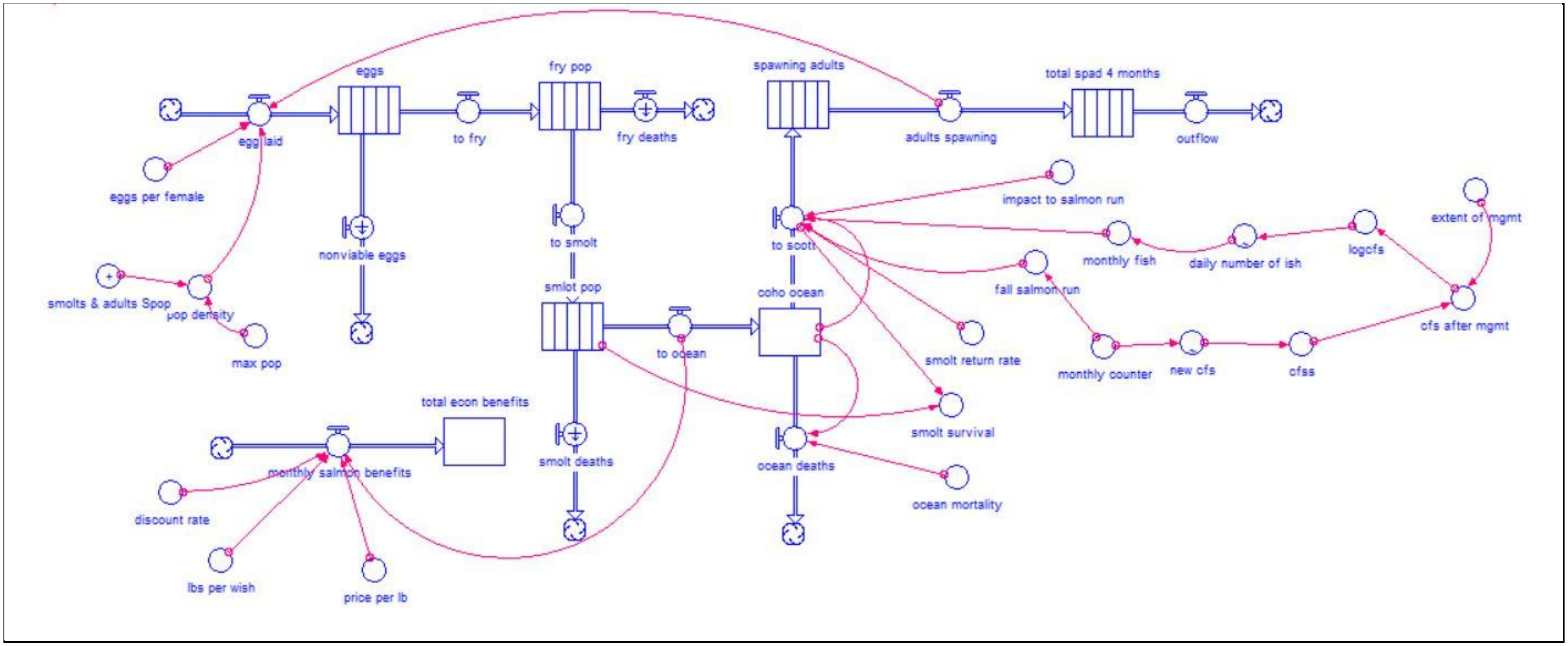

Figure 1A: STELLA population simulation model.

Table 2. Simulation model equations table for stocks, flows, and variables.

Abbreviation	*Name*	*Type*	*Value*	*Units*	*Reference/ Calculation*
Eggs	*Eggs Laid*	*Stock-Converter*	*Initial 3000*	#	*(USDA Soil Conservation Service, 1971)*
Fry Pop	*Fry Population*	*Stock-Converter*	*Calculated*	#	
Smolt Pop	*Smolt Population*	*Stock-Converter*	*Initial 3931*	#	*(Knechtle & Giudice, 2021)*
Coho Ocean	*Coho in Ocean*	*Stock-Bucket*	*Calculated*	#	*Estimated from data set*
Spawning Adults	*Spawning Adults*	*Stock-Converter*	*Initial 1500*	#	*(Knechtle & Giudice, 2021)*
Total Econ Benefits	*Total Economic Benefits*	*Stock-Bucket*	*Calculated*	*USD*	
Eggs Laid	*Eggs Laid*	*Flow*	*Calculated*	#	*adult_spawning/2*eggs_per_female*(1-pop_density)*
Nonvi Eggs	*Non Viable Eggs*	*Flow*	*0.5*	#	*(Dahlberg, 1979)*
To Fry	*To Fry*	*Flow*	*0.5*	#	*(Dahlberg, 1979)*
Fry Deaths	*Fry Deaths*	*Flow*	*0.41*	#	*(Meyer, 2005)*
To Smolt	*To Smolt*	*Flow*	*Calculated*	#	*Inverse of Fry Deaths*
Smolt Deaths	*Smolt Deaths*	*Flow*	*0.203*	#	*(Pisano, 2012)*
To Ocean	*To Ocean*	*Flow*	*0.797*	#	*(Pisano, 2012)*
Ocean Deaths	*In Ocean Deaths*	*Flow*	*Calculated*	#	*cohoocean*ocean_mortality*
To Scott	*To Scott River*	*Flow*	*Calculated*	#	*cohoocean*smolt_return_rate*
Adults Spawning	*Adults Spawning*	*Flow*	*0.93*	*%*	*(Knechtle & Giudice, 2021)*

Monthly Salmon Benefits	*Monthly Salmon Benefits*	*Flow*	*Calculated*	*n/a*	*(to_ocean*price_per_lb*lbs_per_wish)*EXP(-discount_rate/12*TIME)*
Eggs per Female	*Eggs per Female*	*Variable*	*Random, 2000, 4000, 24*	*#/Female*	*(USDA Soil Conservation Service, 1971)*
S&A Spop	*Smolt and Adult Population in Scott River*	*Variable*	*Calculated*	*Total #*	*Smolt_pop + spawning_adults*
Max Pop	*Maximum Population*	*Variable*	*100,000*	*#*	*Calculated*
Popden	*Population Density*	*Variable*	*Calculated*	*#*	*salmon_pop_in_scott_of_smolts_adults/max_pop*
Ocean Mortality	*Ocean Mortality*	*Variable*	*0.5*	*#/year*	*(Magnusson, 2003)*
Smolt Return Rate	*Smolt Return Rate*	*Variable*	*0.095*	*#/year*	*(Knechtle & Giudice, 2021)*
Monthly Counter	*Monthly Counter*	*Variable*	*Calculated*	*Date Range*	*MOD(TIME,12)*
Fall Salmon Run	*Fall Salmon Run*	*Variable*	*Calculated*	*Date Range*	*IF(monthly_counter>=7)AND(monthly_counter<11)THEN(1)ELSE(0)*
% Impact to Run	*Percent Impact to Run*	*Variable*	*Calculated*	*%*	*Calculated*
Smolt Survival	*Smolt Survival*	*Variable*	*Calculated*	*#*	*to_scott/smolt_pop*
Monthly Fish	*Monthly Fish*	*Variable*	*Calculated*	*#/month*	*daily_number_of_ish*30*
Daily number of ish	*Daily Number of Fish*	*Variable*	*Graphical Function*	*#/day*	*Derived from (Knechtle & Giudice, 2021)*
Logcfs	*Log Transform of Cfs*	*Variable*	*Calculated*	*cfs*	*LOG10(cfs_after_mgmt)*
New cfs	*New Cfs*	*Variable*	*Graphical Function*	*cfs*	*Derived from (United States Geographic Survey, 2021)*
Newcfss	*Additional Log Transform of Cfs*	*Variable*	*Calculated*	*cfs*	*(10)^new_cfs*

Cfs After Mgmt	*Cfs After Management*	*Variable*	*Calculated*	*cfs*	*IF(cfss+(extent_of_mgmt)<=0)THEN(0.01)ELSE(cfss+(extent_of_mgmt)*
Extent of Mgmt	*Extent of Management*	*Variable*	*n/a*	*n/a*	*On/Off Switch*
Discount Rate	*Discount Rate*	*Variable*	*0.01 and 0.03*	*#*	*n/a*
Lbs per wish	*Pounds per Fish*	*Variable*	*10*	*#*	*NOAA, n.d.*
Price per Pound	*Price per Pound*	*Variable*	*2.15 and 3.43*	*#*	*NMFS, 2022*

Table 3. Goods and Services of Coho

Function	*Process*	*Service*	*Good*	*Benefit of Water to Salmon*	*Cost of Water not to Salmon*	*Market (M) or Non Market (NM)*
Nutrient Regulation[1]	*Recycling Nutrients*	*Nutrient cycling (nitrogen from coho)*		*Maintain nutrient cycling*	*Lose some nutrient cycling benefits*	*NM*
Biological Control[1]	*Population control through trophic-dynamic relations*	*Coho maintain biological and genetic diversity*	*helps maintain the population that is eventually harvested out at sea*	*Maintain or increase biological and genetic diversity*	*Biological and genetic diversity in ecosystem is threatened*	*M and NM*
Refugium Function[2]	*Suitable living space for animals*	*Maintain and/or increase salmon habitat, help create invertebrate habitat*		*Maintain or increase salmon and other species habitat*	*Maintain or lose salmon and other species habitat*	*NM*
Nursery Function[2]	*Suitable reproduction habitat*	*Coho spawning grounds*	*hunting fish, small scale subsistence of coho*	*Maintain or increase salmon spawning grounds and total*	*Maintain or lose the benefit*	*M and NM*

				exploitable stock		
Food[3]	*Solar energy into edible animal*		*Coho salmon (good, commercial and recreational)*	*Maintain or increase total exploitable stock*	*Maintain or lose the benefit*	*M*
Genetic Resources[3]	*Genetic material and evolution in wild animals*	*Last wild coho population in this area, provides genetic diversity*		*Supports population growth and reduces need on hatchery fish*	*Maintain or lose the benefit and more reliance on fisheries*	*NM*
Ornamental Resources[3]	*Ornamental use*		*For handicraft, fashion, jewelry, worship, decoration, & souvenirs: native tribes and coho skin as leather and bones as regalia*	*Supports native tribes ability to utilize salmon for regalia and other cultural purposes*	*Loss of the benefit*	*NM*
Aesthetic Information[4]	*Attractive landscape features*	*River and coho scenery*		*Maintain or increase river and coho scenery*	*Maintain or lose the benefit*	*NM*
Recreation[4]	*Landscape with potential recreational use*	*Travel to ecosystem for scenery*	*Travel to ecosystem for recreational fishing*	*Maintain or increase scenery and coho population and thus travel for those purposes*	*Maintain or lose the benefit*	*M and NM*
Cultural and Artistic Information[4]	*Cultural value*		*Skin used as leather, bones for regalia, in native cultures*			*NM*
Spiritual and Historic Information[4]	*Spiritual and historic value*	*Use for religious or historic purpose*				*NM*

1. Regulation Functions

2. Habitat Functions
3. Production Functions
4. Information functions