Shrinking Salmon

Part 1: The Shrinking Salmon Problem

Chinook Salmon

Figure 1. Chinook salmon at sea (left) and spawning in a stream (right)

Chinook salmon are an important part of ocean ecosystems. They serve as the major food source for Southern Resident orcas, and they play a key role in the cycling of matter and the flow of energy in this ecosystem. They also play an important part in freshwater ecosystems because Chinook salmon are *anadromous*. This means that they begin their lives in freshwater streams and river habitats, then migrate to the open ocean for most of their lives. As adults, they return to the rivers they were born in to reproduce and, eventually, die. Figure 2 shows the life cycle of the Chinook salmon.

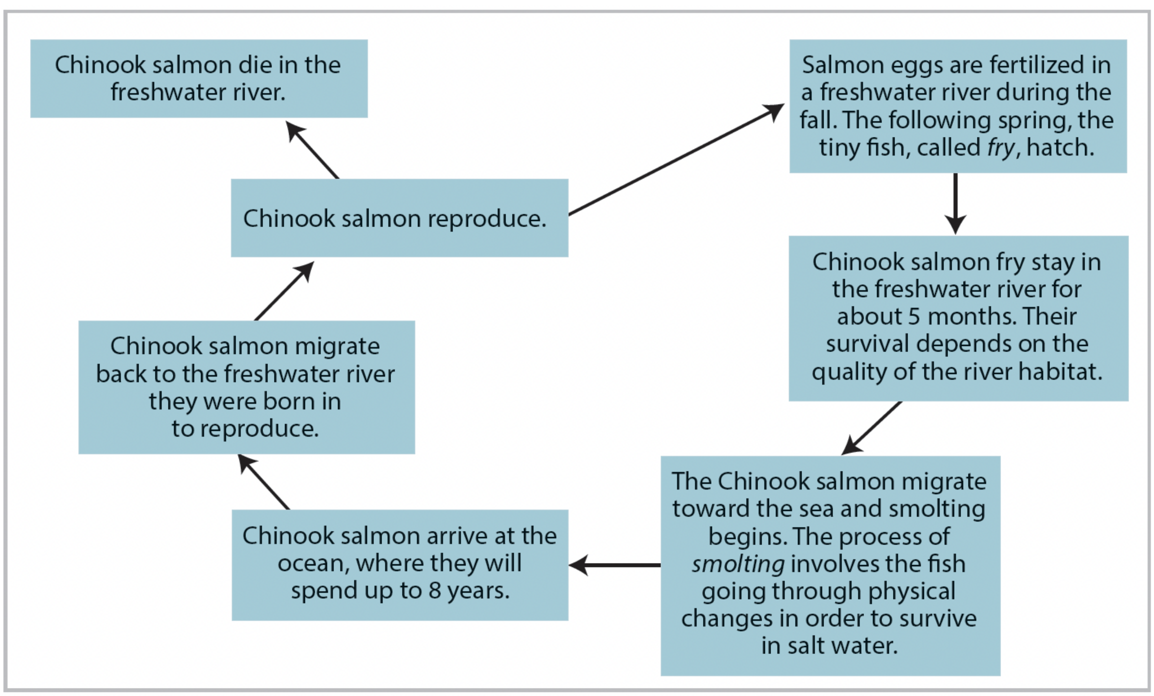

Figure 2. Life cycle of Chinook salmon

Shrinking Salmon Phenomenon

Starting around 1990, Chinook salmon began making their return journeys to breed at a younger age. Age and body size are highly correlated in salmon—*the older the salmon, the larger it is*. But now the average Chinook salmon is younger and smaller than in the past, both at sea and in the freshwater streams, as shown in Figure 3.

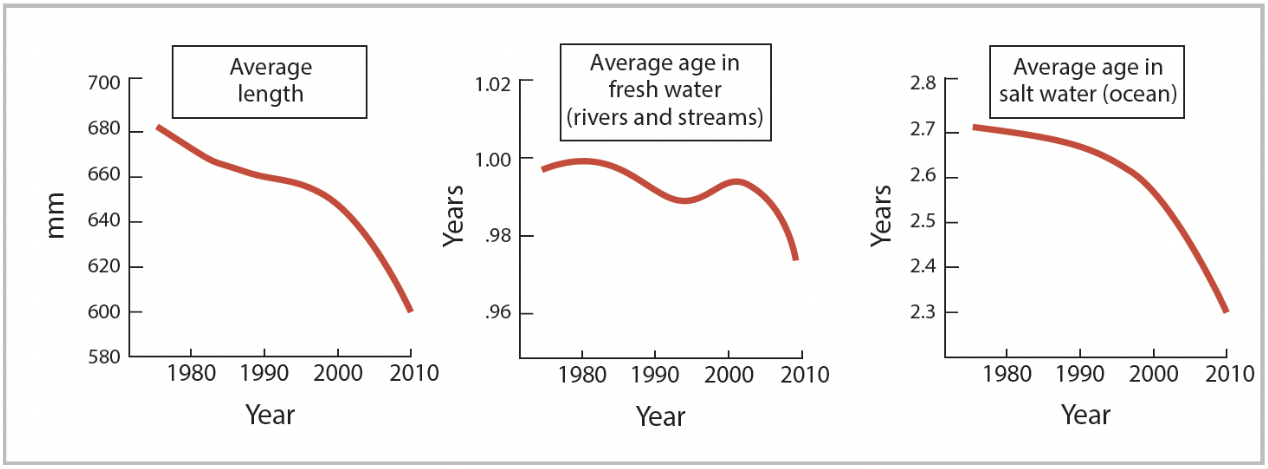

Figure 3. Body size and age of Chinook salmon over time

In addition to being important components in the ocean and the streams where they breed, Chinook salmon are also an important commercial fish, sold in markets and restaurants worldwide. Salmon are important to some rural people as a source of food security, and they also serve as a cultural connection for some groups of people. Thus, there are significant consequences of the reduced body size of Chinook salmon--and therefore less total Chinook salmon biomass--to ecosystems and people. Researchers have calculated that between 1990 and 2010, there was a:

- 16% reduction in Chinook salmon egg production,
- 28% reduction in the flow of nutrients from salmon to other organisms,
- 21% reduction in commercial fisheries earnings, and
- 26% reduction in meals for rural people.

Because of the negative environmental, economic, and social impact of this smaller body size, scientists, conservation biologists and fisheries managers are exploring the causes and possible solutions to this problem.

Driving Question

What is the solution to the “shrinking salmon” problem?

Scientific Findings

Researchers have been tracking several biotic and abiotic factors that may be causing the salmon to return to spawn at a younger age (which results in smaller salmon). Two of the major factors in the ocean are climate change (increasing ocean temperatures) and increased competition from other fish species (both invasive species and fish that have escaped from aquaculture). Two important factors in the freshwater streams are the quality and the depth of the water.

Data collected by these researchers have been used to create a computer simulation to model the effects of four environmental variables on salmon body size. Because the salmon spend part of their lives in the ocean and part in streams, the researchers have identified two variables for each location. In the ocean, the variables are ocean temperature and the level of competition from invasive species of fish and fish that have escaped from aquaculture pens. In the stream, the variables are water quality (which is impacted by pollution from nearby towns) and water level (which is impacted by human development in wetland areas).

Procedure and Analysis

1. Construct an explanation for how "shrinking salmon" is an evolutionary adaptation in response to natural selection. Be sure to explain the trait that natural selection is acting on and how a changing environment results in a change in the frequency of that trait in the salmon population.
2. Create a system model that helps you analyze the problem of decreasing Chinook salmon body size. The system model should identify the relevant components within the system and how the components interact with one another.
3. Use your system model to consider the following questions:
   - What might happen if salmon body size continues to decline?
   - What might be done to address one or more of the problems caused by declining salmon body size?
   - What additional data or information would you want to gather to help you understand this complex real-world problem?

Part 2: Solving the Problem

Computer Simulation

You will design a potential solution to the problems caused by the evolutionary decline in salmon body size. You will use a computer simulation to help you understand the factors affecting the age at which Chinook salmon return to spawn in a typical creek, based on real-world data. You will determine how these factors affect body size and the total amount of Chinook salmon biomass in the system.

The salmon simulation provides data about the change in biomass and the distribution of size classes (small, medium, and large) in salmon over time from 1980 to 2020, and projects these values into the future (to 2060) depending on environmental conditions.

- Part A examines a random sample of 1,000 salmon from the entire population.
- Part B examines the entire population of salmon.
- Part C allows you to test possible solutions based on your results in Parts A and B.

Part A: Factors Affecting Body Size in Salmon

In Part A of the simulation, you will examine a random sample of 1,000 salmon from the entire population. You will look at two dependent variables:

- The total biomass (kg) of 1,000 randomly sampled fish
- The size distribution of 1,000 randomly sampled fish—the percentage of small salmon (average body size 2 kg), medium salmon (average body size 8.5 kg), and large salmon (average body size 14 kg)

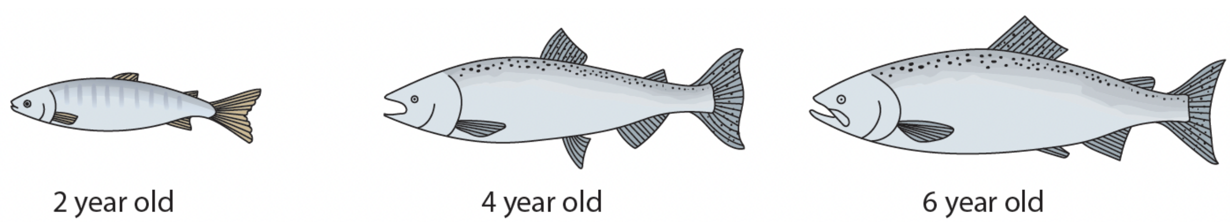

Figure 4. Chinook salmon body size increases with age.

Procedure and Analysis

1. Begin by exploring what has happened from 1980 to 2020.

   Note: The default setting for this simulation assumes that environmental conditions do not change moving forward—that is, the environment will remain in its current state into the future.

2. Explore the four independent environmental variables from your system model in Part 1 to

see their effect on I) total biomass and ii) body size distribution. The two ocean variables are *temperature* and *competition from other species*, and the two stream variables are *water quality* and *water depth*.

3. Use Part A of the Data Collection Sheet to guide your exploration of the simulation. Start by exploring one environmental variable at a time to determine its impact on both the *biomass of the randomly sampled 1,000 fish,* and the *percentage of fish in each size class*. Record the results on the sheet. Then explore the additional factors one at a time, recording the results after each variable. Be sure to reset the simulation each time.
4. Which condition has the greatest evolutionary impact on the age at which salmon return to spawn, and therefore salmon body size? In other words, which environmental variable applies the strongest natural selection favoring salmon that return to spawn at a younger age?

Part B: Factors Affecting Salmon Populations

In Part B of the simulation, you will examine the same independent environmental variables but this time for the entire population of salmon instead of a random sample. You will also record an additional dependent variable: *total population size*.

Procedure and Analysis

5. Explain why you would want to look at the entire population of salmon vs. a sample of only 1,000.

   Hint: Consider whether environmental variables can affect aspects of the salmon population besides body size.
6. Use Part B of the Data Collection Sheet to guide your exploration of the simulation. Start by exploring one environmental variable at a time to determine its impact on the *total biomass of the population*, the *number of fish in each size class*, and the *total population size*. Record the results on the sheet. Then explore the additional factors one at a time, recording the results after each variable. Be sure to reset the simulation each time.
7. Answer the following questions:
   - What are the differences between the results from Part A and from Part B?
   - Which condition is having the greatest total impact on the salmon population? (That is, which environmental variable is having the greatest combined evolutionary impact and the greatest impact on the size of the salmon population?)
   - What are the implications of these differences in terms of managing the salmon population?

Part C: Designing a Solution

In Part C of the simulation, you will design a solution to address the problems caused by the decreased biomass of the Chinook salmon population: reduction in the flow of nutrients from salmon to other organisms (including orcas), reduction in commercial fisheries earnings, and reduction in meals for rural people.

Procedure and Analysis

8. Consider what could be done to sustain or increase the total biomass of the salmon, drawing on your results from Part A and Part B of the simulation. Be sure to think about sustaining or increasing each of the following:
   - The percentage of individual salmon that are classified as large
   - The size of the total salmon population
9. Use Part C of the Data Collection Sheet to guide you through potential solutions to the shrinking salmon problem.
10. Explain which solution seems to be the most effective based on Part C of the simulation. Also address how confident you that your solution will solve the shrinking salmon problem.
11. Consider this: So far you have considered only the *effectiveness* of a particular approach when designing a solution. But not all solutions are equally feasible, and the cost of mitigation strategies can vary tremendously. If money and feasibility are also issues, how would that impact your mitigation strategy?

Data Collection Sheet--Part A

Condition	Biomass of 1,000 randomly sampled salmon (kg) in 1980	Biomass of 1,000 randomly sampled salmon (kg) in 2060	Size class distribution of 1,000 randomly sampled salmon (%) in 1980	Size class distribution of 1,000 randomly sampled salmon (%) in 2060
Default	11.7K kg	8.8K kg	S: 7% M: 26% L: 67%	S: 29% M: 31% L: 40%
Ocean Warming			S: M: L:	S: M: L:
Competition in the Ocean			S: M: L:	S: M: L:
Stream Water Quality			S: M: L:	S: M: L:
Stream Water Depth			S: M: L:	S: M: L:

Data Collection Sheet--Part B

Condition	Biomass (kg) of total population in 1980	Biomass (kg) of total population in 2060	Size class distribution of total population in 1980	Size class distribution of total population in 2060	Total population size in 1980	Total population size in 2060
Default	2.33M kg	1.19M kg	S: 15K M: 52K L: 132K	S: 39K M: 43K L: 54K	199K	136K
Ocean Warming			S: M: L:	S: M: L:		
Competition in the Ocean			S: M: L:	S: M: L:		
Stream Water Quality			S: M: L:	S: M: L:		
Stream Water Depth			S: M: L:	S: M: L:		

Data Collection Sheet--Part C

Solutions	Biomass (kg) of total population in 2020	Biomass (kg) of total population in 2060	Total population size in 2020	Total population size in 2060	Size class distribution of 1,000 randomly sampled salmon (%) in 2020	Size class distribution of 1,000 randomly sampled salmon (%) in 2060
No Action	1.4M kg	273K kg	160K	112K	S: 29% M: 31% L: 40%	S: 94% M: 4% L: 2%
Ocean Warming **________% Improvement**					S: M: L:	S: M: L:
Ocean Warming **________% Improvement**					S: M: L:	S: M: L:
Competition in the Ocean **________% Improvement**					S: M: L:	S: M: L:
Competition in the Ocean **________% Improvement**					S: M: L:	S: M: L:
Stream Water Quality **________% Improvement**					S: M: L:	S: M: L:
Stream Water Quality **________% Improvement**					S: M: L:	S: M: L:
Stream Water Depth **________% Improvement**					S: M: L:	S: M: L:
Stream Water Depth **________% Improvement**					S: M: L:	S: M: L: